MECHANICAL ENGINEERING

INCLUDING THE ENGINEERING INDEX

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Spring Meeting Papers

This supplement to the May issue of MECHANICAL ENGINEERING presents a number of the papers that will be read at the meeting and brings information about others that are available in pamphlet form to those who request them. It is the sincere hope of the Committee on Meetings and Program and the Committee on Publications that these papers, published as they are well in advance of the meeting, will arouse discussion at the meeting that will contribute equally with them to the value of the Society's published records.

Be sure to bring this copy to the Meeting

MAY 1925

THE MONTHLY JOURNAL PUBLISHED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Mechanical Engineering

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The Purpose of This Supplement

THIS special supplement to the May issue of MECHANICAL ENGINEERING brings advance information about the Program of the Milwaukee Spring Meeting of the A.S.M.E., together with the text of a number of complete papers and synopses of others that are available in pamphlet form. Copies of the latter may be obtained by filling in the form on page 447. This supplement, however, should be brought to the Meeting, as copies of the papers appearing in it will not be available for free distribution. However, additional copies of the supplement may be purchased at the Meeting.

It is the purpose of this supplement to make available to the members of the A.S.M.E. information regarding the papers that are to be presented, so that discussion at the Meeting will be well considered and thoughtfully prepared.

As it is the purpose of a meeting of the Society to secure the greatest possible participation by all of those who attend, it is highly desirable that members have advance information as to the subject-matter of the papers that are to be read at the meeting. It is a waste of valuable time for an author to read a technical paper from beginning to end at a meeting, for the audience is seldom able to evaluate statements that are made and compare them with their own experience. Further, there is a limit to the amount of time during which interest in the presentation of a technical paper can be maintained.

It has been the effort of the Committee on Meetings and Program to stimulate discussion at the meetings of the Society, knowing that a spirited discussion insures an interesting meeting. Discussion greatly strengthens the permanent value of the papers presented at the meeting. A paper which has been subjected to the fire of public criticism or warmed by the addition of corroboratory information is, when properly recorded, of much greater value as a part of the permanent literature of mechanical engineering than a spiritless or an uncriticized contribution. In some cases the discussion may be of even greater value than the paper. From its value in instilling interest in the meeting and from its effect on the record of the meeting, discussion is therefore vitally essential. The Committee on Meetings and Program and the Committee on Publications have coöperated in this procedure for presenting and issuing papers for the Milwaukee Spring Meeting.

The Milwaukee Spring Meeting

MILWAUKEE is the place for the 1925 Spring Meeting of The American Society of Mechanical Engineers. The dates are from May 18 through 21, and the headquarters will be the Hotel Pfister. The program on the opposite page includes the technical sessions and a mention of the interesting entertainments and excursions which the Milwaukee Committee is planning. The current issues of the *A.S.M.E. News* are giving particulars of the many interesting events that are to be held during the four days of the meeting.

Milwaukee is a city of diversified industries, and members engaged in all phases of mechanical engineering will find much of interest and value in the program.

The American Society of Refrigerating Engineers will hold a meeting in Milwaukee simultaneously with that of the A.S.M.E., and on the afternoon of Thursday, May 21, there will be a joint hearing on the Test Code for Refrigerating Apparatus.

MECHANICAL ENGINEERING

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Tentative Spring Meeting Program

Hotel Pfister—Milwaukee, May 18–21, 1925

Monday, May 18

Morning:
Meeting of A.S.M.E. Council
Local Sections Conference

Afternoon:
Business Meeting of Society
Meeting of A.S.M.E Council
Boiler Code Public Hearing
Excursions: Sewage Disposal Plant; Palmolive Company; Phoenix Hosiery Company

Evening:
Reception

Tuesday Morning, May 19, 9:30 A.M.

Machine Shop

Recent Investigations in Turning and Planing and a New Form of Cutting Tool, H. Klopstock.
A Code of Design for Mechanical Springs, J. K. Wood.
Defects in Large Forgings, J. Fletcher Harper.

Hydroelectric

The Parallel Operation of Hydro and Steam Plants, F. A. Allner.
Mechanical Features Affecting the Reliable and Economical Operation of Hydroelectric Plants, E. A. Dow.
Mechanical Problems of Hydraulic-Turbine Design, Wm. M. White.

Forest Products

A New Era in Forestry, H. F. Weiss.
Standardization of Grading Rules for Hardwood Lumber, A. T. Upson.

Pulverized Coal

A Microscopic Study of Pulverized Coal, L. V. Andrews.
Boiler Furnaces for Pulverized Coal, A. G. Christie.
Radiation in the Pulverized-Fuel Furnace, W. J. Wohlenberg and D. G. Morrow.

Tuesday Afternoon

Excursions

Allis-Chalmers Mfg. Co.
Eline's, Inc. (Chocolate) powdered-fuel plant.
Robt. A. Johnston Co., manufacturers of candies, crackers and cookies.
Kearney & Trecker Company.

Student Branch Conference

Tuesday Evening

Musicale

Visit to Central Continuation School

Milwaukee Session

The Activated-Sludge Sewage-Disposal Plant at Milwaukee, John A. Wilson.
Critical Study of Heat and Power Requirements of Sewage-Disposal Plants, Robt. Cramer.
Duty Tests of Vertical Triple-Expansion Pumping Engines, Milwaukee, Wis., Charles A. Cahill.
The Economical Advantage of Cities Having Diversified Industries, (Author to be announced.)

Wednesday Morning, May 20, 9:30 A.M.

Materials Handling

Formulas for Computing the Economies of Labor-Saving Equipment, J. A. Shepard and G. E. Hagemann.
An Application of the Formulas for Computing Economies of Labor-Saving Equipment, Geo. Langford, Jr.
Labor-Saving Equipment in Road Construction, E. H. Lichtenberg and J. A. Shepard.
Economic Efficiency of the Full-Automatic Turret Lathe in Comparison with the Semi-Turret Lathe, R. J. Wadd.

Industrial Power

Torsional Vibrations and Critical Speeds of Shafts, A. Lack and C. B. Jahnke.
Tests of a Uniflow Engine, G. H. Barrus.

National Defense

On the invitation of the War Department and the A.S.M.E., manufacturers of Wisconsin will meet to go over the industrial-preparedness plans in Wisconsin based on the allocations of materials to be manufactured in that district.

Materials

The X-Ray Examination of Steel Castings, I. E. Moultrop and E. W. Norris.
Aluminum and Its Light Alloys, R. L. Streeter and P. V. Faragher.
Stress Concentration Produced by Holes and Fillets, S. Timoshenko and W. Dietz.

Wednesday, Afternoon

Excursions

Vilter Mfg. Co.
Riverside Pumping Station.
Falk Corporation.

Public Hearing, Power Test Codes

Test Code for Centrifugal and Rotary Pumps.
Test Code for Reciprocating Steam-Driven Displacement Pumps.

Wednesday Evening

Dinner

Public Meeting

Assistant Secretary of War Davis as principal speaker.

Thursday Morning, May 21, 9:30 A.M.

Steam Power

A Review of Steam-Turbine Development, HANS DAHLSTRAND.
Rational Design of Covering for Pipes Carrying Steam up to 800 Deg. Fahr., W. A. CARTER and E. T. COPE.
Lake Waters for Condensers, A. G. CHRISTIE.
Analysis of Power-Plant Performance Based on the Second Law of Thermodynamics, W. L. DEBAUFRE.
Comparison of Actual Performance and Theoretical Possibilities of the Lakeside Station, M. K. DREWRY.

Management

Steel-Foundry Management, R. A. BULL.
Management of Gray-Iron Foundries, G. P. FISHER.
Report of Committee on Elimination of Unnecessary Fatigue, GEO. H. SHEPARD.

Apprenticeship

A National Apprenticeship Program, HAROLD S. FALK.
Milwaukee District Apprenticeship Scheme (Author to be announced).

Railroad

Factors Concerning the Economics of Shopping Steam Locomotives, L. K. SILLCOX.
Freight-Car Maintenance, C. G. JUNEAU.

Thursday Afternoon

Excursions

Lakeside Power Station.
Nordberg Mfg. Company.

Public Hearing with A.S.R.E.

Test Code for Refrigerating Systems.

The X-Ray Examination of Steel Castings

By I. E. Moultrop[1] and E. W. Norris,[2] Boston, Mass.

The rapid development of power-station design toward higher pressures and temperatures necessitates a corresponding improvement in the qualities of the materials used for equipment. The physical properties must be better, and these properties must be realized not only in the laboratory but also in the commercial product. We can no longer rely on a conservative factor of safety to counteract possible flaws, for many modern designs prohibit large excesses of metal, and experience indicates that flaws involve not only an initial weakness but also a tendency toward deterioration during service. It is therefore necessary to eliminate flaws rather than to provide excess metal to compensate for them.

This situation is by no means new. The history of materials manufacture is a record of laboratory study and the gradual application of laboratory methods to commercial processes. This paper discusses one of the latest of these methods to be thus applied, that is, the use of X-rays.

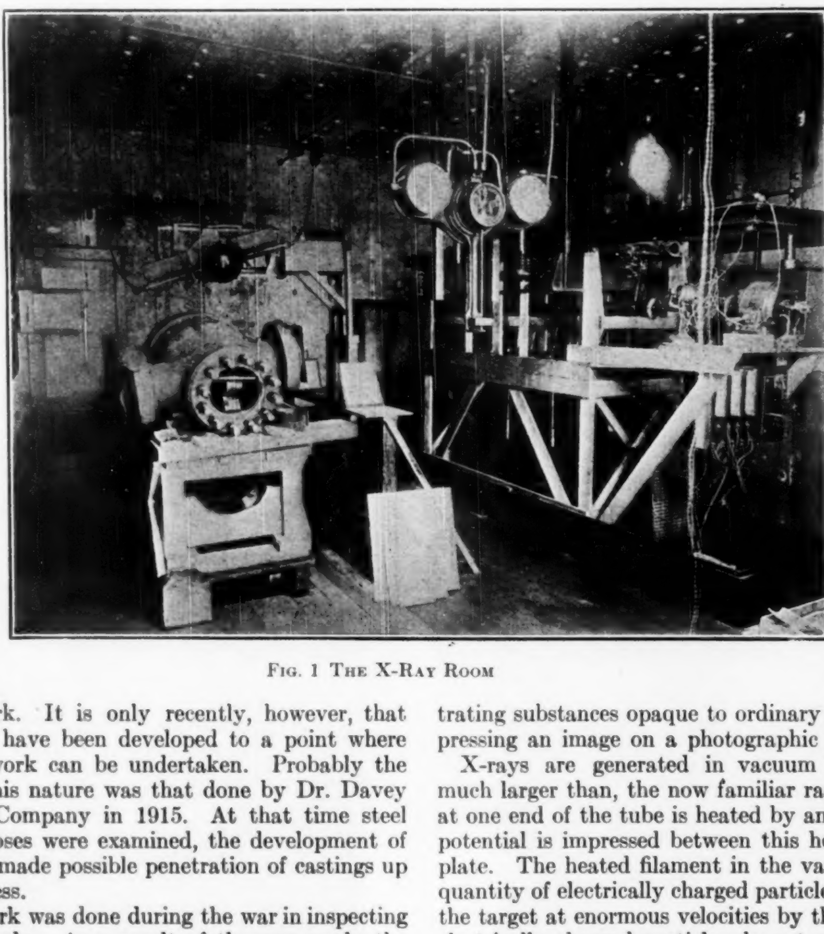

Fig. 1 The X-Ray Room

Development of X-Ray Examination

The examination of materials by X-rays was suggested in the very early days of X-ray work. It is only recently, however, that apparatus and technique have been developed to a point where satisfactory commercial work can be undertaken. Probably the first successful work of this nature was that done by Dr. Davey of the General Electric Company in 1915. At that time steel castings for various purposes were examined, the development of the Coolidge tube having made possible penetration of castings up to a considerable thickness.

A certain amount of work was done during the war in inspecting munitions of various kinds. As a result of the war work, the Watertown Arsenal at Watertown, Mass., under the direction of Col. T. C. Dickson, has developed the technique of X-ray photography of metals, and especially of steel castings, in conjunction with a corresponding development of foundry practice. Their efforts have been most successful and many difficult castings have been made commercially possible by the insight into their quality obtained through X-ray work.

The X-rays do not possess any peculiar property that improves a given material, but they furnish a means by which its innermost structure may be examined and, to a considerable degree, analyzed without damage. The value of such an examination is twofold: the soundness of the material can be tested, and the location and character of flaws can be determined. The causes of flaws can be suggested by checking against the details of the processes of manufacture. In this way a foundation is laid for the elimination of flaws by the improvement of manufacturing processes brought under suspicion.

At the present time the most important metallurgical application of X-ray methods is in the study of steel castings. Careful work along this line enables the foundry to turn out work that compares favorably with that of the forge. The advantages to be thus obtained are obvious and amply warrant the most careful consideration.

X-Rays and X-Ray Apparatus

X-rays do not differ fundamentally from light rays. They are waves in the same medium and of the same character as light waves. They are, however, of very much shorter wave length and have the power of penetrating substances opaque to ordinary light waves, and also of impressing an image on a photographic plate.

X-rays are generated in vacuum tubes similar to, but very much larger than, the now familiar radio tube. A small filament at one end of the tube is heated by an electric current, and a high potential is impressed between this heated filament and a target plate. The heated filament in the vacuum tube gives off a large quantity of electrically charged particles which are directed against the target at enormous velocities by the electric potential. These electrically charged particles do not constitute X-rays, but when they strike the target their energy is released and is transformed in some way into the vibrations radiated by the target as X-rays.

The penetrating power of the X-rays generated by a tube depends very largely upon the velocity at which the charged particles are projected against the target; which again depends on the voltage between the filament and the target plate. This voltage varies from some 20,000 or 30,000 upward. For the examination of heavy castings very high voltages must be resorted to in order to obtain sufficient penetrating power to produce satisfactory photographs or "radiographs." At the present time, the commercial limit is about 250,000 volts, which gives a maximum penetration of approximately 3 in. of steel. Under favorable conditions this may be extended to 4 in. This suffices for a large part of the work required, but falls short of the penetration needed for the heavy flanges, etc. on ultra-high-pressure equipment. It is estimated that an

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[2] Engineer, Mechanical Division, Stone & Webster, Inc. Mem. A.S.M.E.

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operating voltage of 600,000 can be successfully applied, which would give a penetration of approximately 6 in. Unfortunately, up to the present time means have not been available to carry on the research necessary to develop this equipment.

X-rays have the peculiar quality of setting up secondary radiation in almost all substances. Thus, when a metal plate is penetrated by X-rays, secondary radiation is generated by the metal itself, which glows, as it were, with an invisible radiance. This radiation is very similar to the X-rays generated by the tube and is capable of impressing a photograph plate. It is frequently a source of difficulty, as special care is required to filter out the indirect radiation so as not to blur the shadows cast by the direct radiation from the tube.

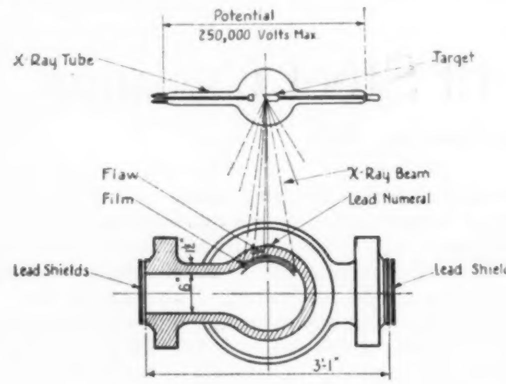

Fig. 2 Set-Up for X-Ray Picture

In making an X-ray photograph or radiograph of an object, the X-ray tube is set up over the portion to be examined and a photographic plate or film is placed immediately beneath the material. The rays penetrate the material and impress the plate. Various thicknesses or densities of material absorb varying amounts of rays, or in other words, cast shadows of varying density on the plate. These form an image which may be made visible by developing the plate in the usual way. Obviously, therefore, the radiograph is a shadow picture of the material being studied. The features shown are approximately full size, and the depth of tone of the negative shows the comparative density or thickness of the material. A hole or thin spot allows more rays to reach the plate, and appears as a dark outline on the negative and vice versa. The method is extremely sensitive, for variations of density or thickness of 2 per cent can be definitely detected. The ordinary flaws of commercial castings that are of enough importance to warrant consideration are equivalent to variations of ten or twenty per cent or more. These can therefore be detected and their importance weighed with a satisfactory degree of accuracy.

The apparatus for X-ray work (Fig. 1) is comparatively simple. The tube itself is supported on a stand which is adjustable for various positions. Flexible lead wires run to the power source with a milliammeter to indicate the current flow through the tube. Power is supplied by a step-up transformer and rectified by a commutator driven by a synchronous motor. The commutator consists of a series of revolving arms which just clear current collectors in the form of circular arcs. These are so located that a proper path is provided for the current to maintain a direct pulsating voltage across the terminals as the commutator revolves.

As X-rays are very injurious to human tissue when subject to frequent exposure, the X-ray equipment is housed in a room lined with quarter-inch lead. The control panel is located outside the room. To give the operator a view of the tube and other equipment a lead-lined periscope is provided which takes advantage of the fact that ordinary light rays are reflected by mirrors that absorb or transmit the X-rays.

When a casting is to be examined, a careful study is made to determine the critical parts. Then the best method of radiographing

Fig. 3 Radiograph of Gas Pockets, Full Size

Fig. 4 Radiograph of Sand Inclusions, Full Size

these is decided on. The parts are then numbered plainly, and the casting is photographed in the ordinary way to locate the numbered sections for future reference.

In taking the X-ray pictures the casting is placed so that the desired area is directly in line with the path of the X-rays from the tube, which is located above or at one side. See Fig. 2. A lead

Fig. 5 Radiograph of Shrinkage Flaws, Slightly Reduced

Fig. 6 Radiograph of Pipe, Slightly Reduced

Fig. 7 Radiograph of Pipe, Slightly Reduced

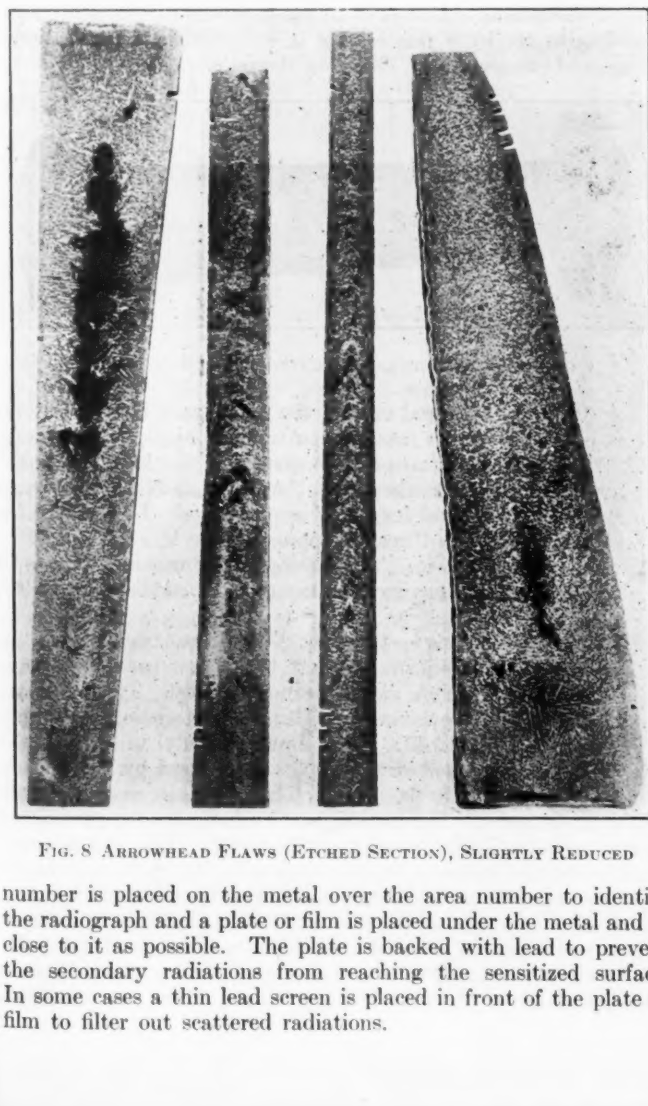

Fig. 8 Arrowhead Flaws (Etched Section), Slightly Reduced

number is placed on the metal over the area number to identify the radiograph and a plate or film is placed under the metal and as close to it as possible. The plate is backed with lead to prevent the secondary radiations from reaching the sensitized surface. In some cases a thin lead screen is placed in front of the plate or film to filter out scattered radiations.

The exposure may be anything up to thirty minutes or more, depending on the thickness of metal to be penetrated. During long exposures it is necessary to stop occasionally to allow the tube to cool down. This frequently doubles the actual time required.

If the section of metal is uniform in thickness the penetration is correspondingly uniform. Where there is a marked change, as at a rib or a flange, there is a tendency to overexpose the thin section in order to penetrate the heavy section. This is counteracted by covering the thin part with a light screen of lead. This protects the thin section and allows much better penetration of the thick section. There is no chance of confusing this "mask" with a flaw as the edge is cut clear and sharp—quite different from the jagged outline of a crack.

The outline of flaws as shown on the radiograph is an exact reproduction of the flaw in the metal, except that there is a certain amount of parallax. This is due to the projection of the rays from a center on the target of the X-ray tube to the photographic plate or film. This is often exaggerated by the use of a film curved to fit the interior of a cylindrical surface.

Fig. 9 Radiograph of Cracks, Slightly Reduced

Flaws Observable

The defects observable in steel castings as determined by the inspection and checking of hundreds of specimens may be grouped under a few general types:

Gas pockets (Fig. 3) are usually clearly defined spherical cavities, though they are often irregular in shape with a rounded outline. They show on the radiograph as rounded spots. Sometimes the gas has moved through the metal leaving a bore like a worm hole which shows a picture rather like a small comet. These cavities may be caused by failure to remove the gas from the metal before pouring; or they may come from sand or dirt in the mold, which generates gas under the high temperatures of the steel. Sometimes the gas pockets are caused by steam from a damp mold.

Sand may be washed from a poorly rammed mold and be covered by the metal. These sand inclusions (Fig. 4) sometimes represent a considerable volume. They may be invisible from the surface of the casting. In the radiograph they show as cloudy areas of irregular outline. When the sand is reasonably free from dirt or binding compound no gas is formed, but the sand inclusions represent areas subject to extremely rapid erosion when the surface metal has been penetrated.

Pipes and voids caused by the shrinkage of the metal during solidification are the most common fault to be found in steel castings. (Fig. 6.) In many cases these flaws are not serious but in others they are extremely so. (Fig. 7.) As the metal in a mold cools it shrinks. The surfaces solidify and tend to pull away from the interior which is still viscous. The gates and risers form reservoirs of metal that remain molten and feed in additional metal during the shrinkage period of the main parts. If this feeding is complete the result is a sound casting; but frequently the flow of metal is retarded and the more remote sections shrink away from the core, leaving a spongy section between two sound walls. (Fig. 8.) This is usually not serious, as the factor of safety is ample to take care of the weakness of the core. It sometimes happens, however, that gas is forced into this spongy metal, exaggerating its weakness. Again, the secondary strains of cooling set up forces that may produce subsurface cracks which are a source of danger whenever the casting is placed in severe service. On the radiograph the spongy shrinkage voids show as fernlike patterns. These develop into "stream lines" when the metal has a well-defined core, and into jagged lines when cracks are formed.

Cracks are probably the most dangerous fault that must be detected, for they have the well-known tendency to increase during service. Cracks are clearly defined on a radiograph when the rays pass through the metal in the plane of the crack (Fig. 9). When the rays strike through obliquely, the image becomes hazy and may be altogether lost. For this reason, when cracks are suspected, it is desirable to take a series of radiographs at varying angles so as to detect cracks running on different slopes.

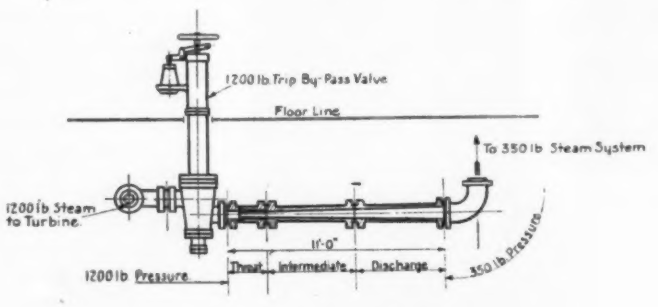

Fig. 10 Arrangement of Nozzle

Weymouth Power Station Work

The work covered by this paper was undertaken in connection with the construction of the Weymouth Power Station of the Edison Electric Illuminating Company of Boston. Part of the steam-power generating equipment at this plant operates at 1200 lb. pressure. This is the first commercial installation at so high a pressure and it was decided to take the precaution, unique in power-plant engineering, of applying X-rays to the inspection of the materials involved.

In examining the equipment careful consideration was given to the general features of the problem before any specialized work was begun. The high-pressure feedwater lines were considered as presenting no problems that have not already been solved in connection with high-pressure hydraulic work. It was therefore deemed unnecessary to use X-ray examination in connection with these. The steam fittings, however, presented the double problem of high pressures and temperatures, with the characteristic of high-pressure steam to increase inherent flaws during service.

The materials selected for high-pressure steam service were forged and cast steel and monel metal. The monel metal used as valve trimming, etc. is not subject to sufficiently critical mechanical stresses to warrant its special examination. Steel forgings have proven so reliable in actual service that the routine tests and analyses are considered entirely satisfactory proof of quality. Steel castings, however, have occasionally shown flaws which could not be detected by any of the ordinary inspection methods, and it was therefore decided to use X-ray photographs as a means of insuring the desired quality of product.

The castings for this work are all special; it was therefore impossible to use the X-ray examination as preliminary test of foundry practice, but the importance of the castings fully justified the expense of individual radiographic tests.

All examinations were made at the Watertown Arsenal. The X-ray laboratory is under the direction of Dr. Lester, to whom the authors are indebted for much of the technical data presented.

In general the castings were examined in the rough so as to avoid doing any machine work on castings which might be rejected. After examination, castings were divided into numbered areas chosen so as to cover the critical parts, as already described. For instance, valve bodies were examined with great care in the neighborhood of the flanges, to determine the soundness of the metal at these points of concentrated stresses. Radiographs were then made covering these areas and the results were carefully studied in connection with the casting itself. Slight shadows on the radiographs were frequently found to be caused by surface irregularities on the casting. For instance, a line of pattern numbers slightly raised above the surface of a casting were very clearly shown on the corresponding radiograph.

In order to check the interpretation of the X-ray work a condemned casting showing a large number of characteristic flaws was carefully cut into sections so as to expose the flaws, and these were then etched and compared with the radiographic negatives. Chemical and physical tests were also performed as a check on the work and it was found that in every case the original interpretation of the radiograph was fully borne out by the character of the casting at the point of examination.

In connection with this work a special effort was made to lay the results of the examinations before the manufacturer producing the casting so that through coöperation the occasional flaws discovered could be eliminated.

Examples of Work

Turning to actual examples of the castings examined, perhaps the most interesting is a nozzle section. This proved to be seriously flawed, containing examples of all the more common faults. After deciding to condemn this casting it was sectioned as mentioned above and examined as a check on the radiographic work.

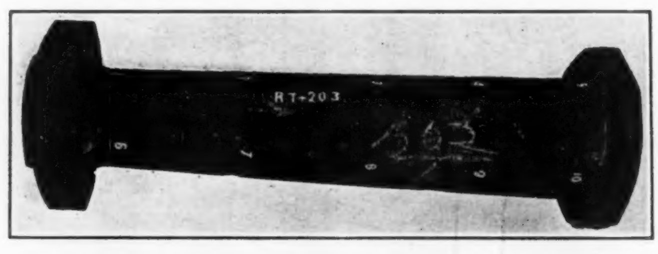

Fig. 11 Nozzle Exterior, Showing Areas Radiographed

Fig. 10 shows a general view of the nozzle as it is installed. It forms part of a bypass intended to transfer high-pressure steam at 1200 lb. to the normal-pressure system at 350 lb. The nozzle is made in three sections, the throat, the center, and the low-pressure section. It has a total length of approximately 11 ft. The internal diameter at the throat is approximately $1^3/_4$ in., and at the low-pressure end, $9^3/_4$ in. The casting under consideration is at the low-pressure end having a maximum internal diameter of $9^3/_4$ in.

For examination this casting was divided into twenty areas for radiographs. Four radiographs were taken near each flange, and twelve at various points along the nozzle body. These sections were arranged as shown in Fig. 11. Characteristic radiographs are shown in Figs. 12–15. They show the metal in the body of the casting. The small circular spots are caused by gas pockets of corresponding size in the metal. The actual size averages about $^1/_8$ in. in diameter. The fernlike pattern indicates the presence of shrinkage voids in the interior of the metal. This is not necessarily a serious weakness as it is caused by the sponginess of the metal between the sound faces. In this case there is a distinct tendency for the sponginess to become continuous, resulting in incipient cracks and a general porosity of the section which would probably tend to form leaks after a period of service. Figs. 14 and 15 show the appearance of the metal at the flanges. Here the condition

is quite serious; gas and shrinkage voids are indicated through the entire body of the material, and in addition the presence of sand inclusions is indicated by the cloudy shadows shown on the radiograph. In Fig. 15 a dark line at the fillet indicates the presence of a crack at the base of the flange at this point.

Following the X-ray examination the casting was cut into sections. Two cross-sections were taken from the body of the nozzle. Longitudinal sections were then made through the flanges and these sections were deeply etched so as to develop the structure of the metal and make the flaws easily visible. Fig. 16 shows the relation of the longitudinal sections and one of the cross-sections. It is at once evident that the metal is extremely porous due to shrinkage voids and has a large number of gas cavities. The most serious feature, however, is the fine shrinkage cracks reaching from the fillet back of the flange and the large cracks running from the interior of the nozzle up into the center of the flange where they meet a highly porous section. This condition is probably caused by improper mold structure. It is probable that the metal flowed out around the end of the core so that on cooling it was impossible for the pipe section to shrink properly along the core and the end was subjected to considerable tension which caused the cracks running up into the core center. Apparently, also, the body of the mold exerted too much pressure on the back faces of the flanges so that a tension stress was concentrated at the flange fillet, causing the fine cracks to form. These flaws certainly rendered the casting unfit for use and their detection may be considered as fully justifying the use of X-ray examination.

A study of the physical and chemical qualities of the material in this nozzle shows that it would have been of high quality had the molding work been successful. A number of specimens were cut from different parts of the nozzle and tested in a tension machine. In general the metal where sound showed satisfactory characteristics, but there was a very decided tendency toward undue brittleness. The appearance of the tension-test specimens is shown in Fig. 17. These specimens show that in the region of flawed material, while the strength is affected to some degree, the elongation and reduction of area are reduced very markedly indeed. Fig. 18 shows a characteristic photomicrograph of the material; the dark spots indicate microscopic cavities, and the general coarseness of the structure is indicated by the dendritic formation clearly shown at the side of the photomicrograph.

The study of this casting in connection with the radiographs gave a very positive check on their interpretation. It formed a basis for comparison with the results obtained from other castings so that the work could be interpreted with confidence.

A further example of the application of X-ray work is the governor-valve body for the high-pressure turbine. This valve body is a rather intricate casting comprising a double-beat valve and a steam-strainer shell in one casting. Fig. 19 gives the general idea of the appearance of the casting. Owing to the complicated internal structure required by the valve ports, the location of X-ray photographs was rather difficult and it was necessary to make a number of comparatively small radiographs in order to develop the quality of the material.

In general the casting was found to be satisfactory, but parts were rather gassy and there was a noticeable amount of dirt in the steel. Fig. 20 shows a characteristic radiograph of the poorer part of the casting.

The flaws shown were in general of rounded form and not of the irregular type which tend to form cracks. As the working stress in the metal is comparatively low it was decided to accept the casting, subject to hydrostatic test for leakage and extensometer test for elastic limit.

Fig. 12 Radiograph of Area 14, Slightly Reduced

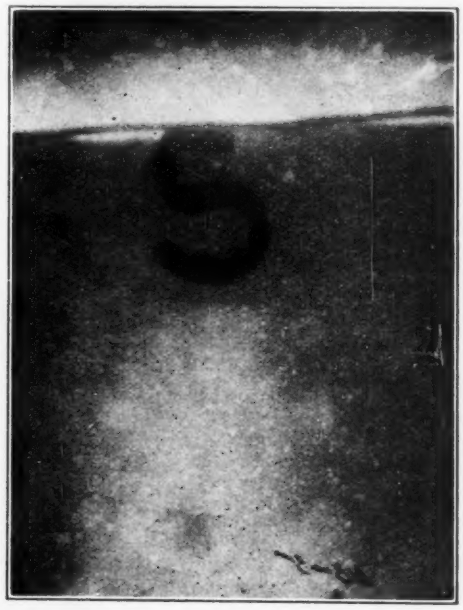

Fig. 14 Radiograph of Area 5, Slightly Reduced

Fig. 13 Radiograph of Area 19, Slightly Reduced

Fig. 15 Radiograph of Area 20, Slightly Reduced

After machining, the casting was blanked off for hydrostatic-pressure test. Before applying the pressure, stops were welded to different parts of the casting for micrometer-gage application. The casting was then measured to give the initial micrometer readings and the water pressure applied. The micrometer readings were repeated under various pressure steps and found to increase very uniformly up to a pressure of 5000 lb., which was the maximum test pressure stipulated. No leaks developed and the pressure was then released, the micrometer readings being repeated. The casting returned very nearly to its original dimensions within a few seconds, but half a minute elapsed before the original dimensions were completely regained. This lag is considered as an indication that the

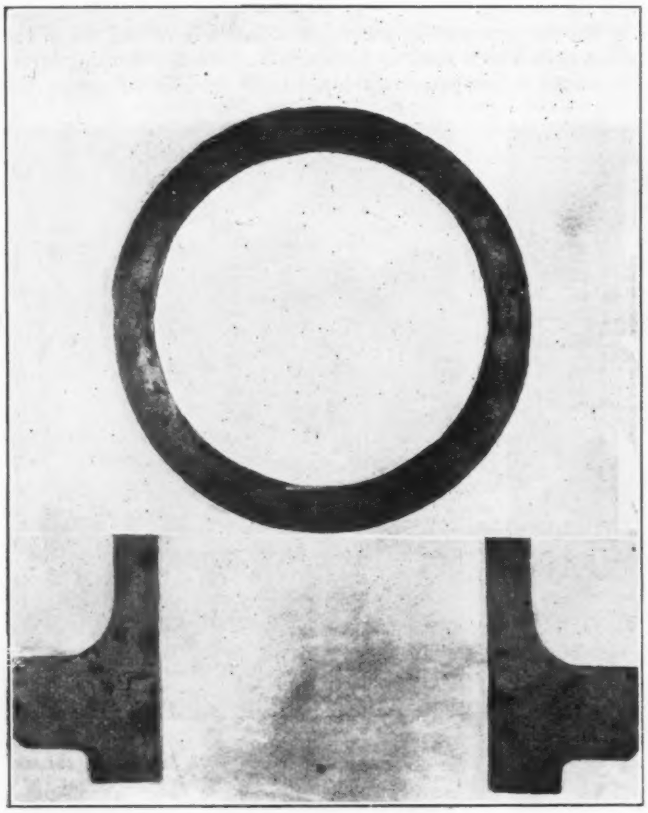

Fig. 16 Etched Sections (Photograph), Slightly Reduced

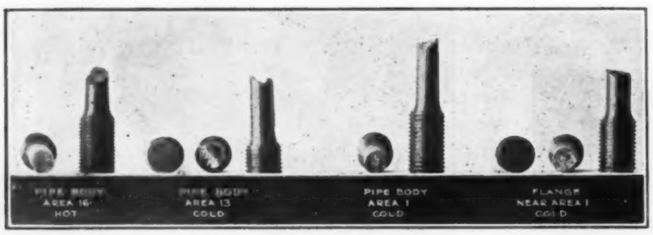

Fig. 17 Test Specimens

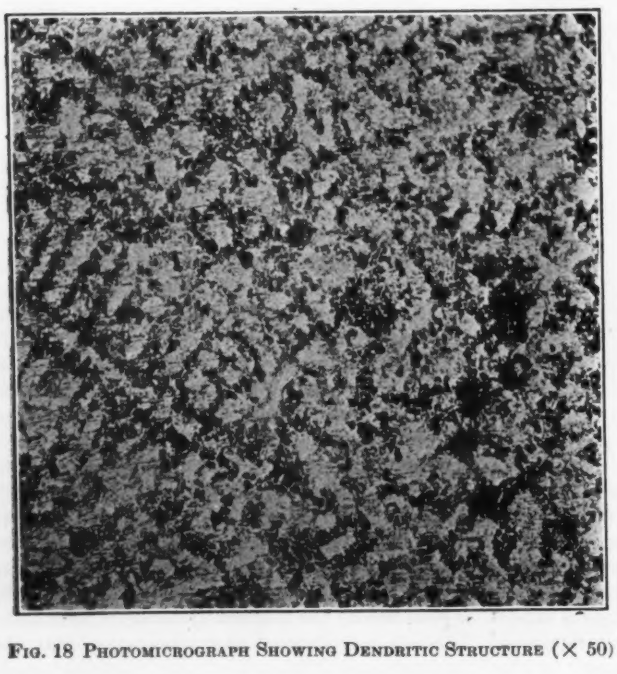

Fig. 18 Photomicrograph Showing Dendritic Structure (× 50)

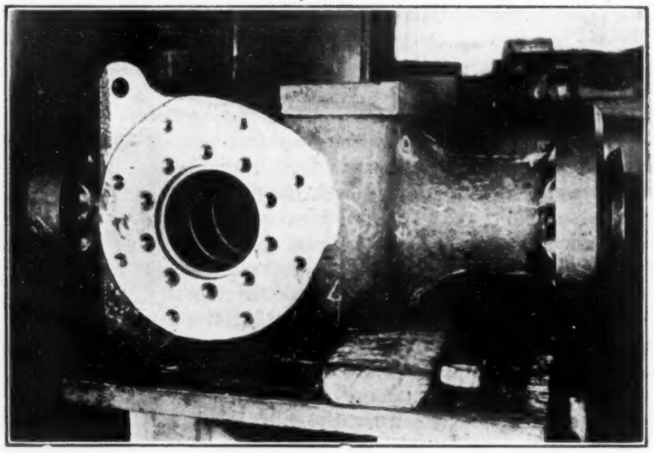

Fig. 19 Valve Body

Fig. 20 Radiograph of Valve Body Shown in Fig. 19, Slightly Reduced

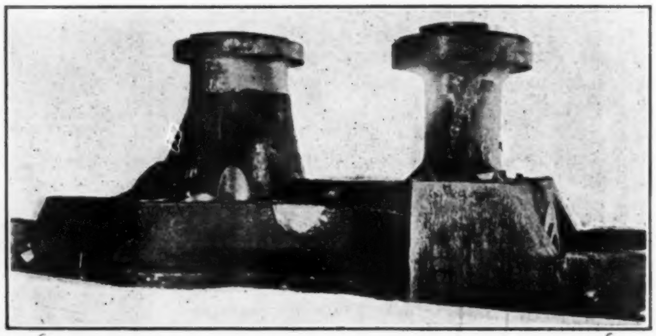

Fig. 21 Exterior of Bottom Half of Turbine Casing

Fig. 22 Radiograph of Inlet-Nozzle Flaws, Slightly Reduced

elastic limit of the material was closely approached, but inasmuch as the original dimensions were completely regained it is assumed that the elastic limit was not exceeded. These measurements under high pressures are considered very important as demonstrating approximately the elastic limit under service conditions. In this case they show positively that the operating pressure of 1200 lb. is protected by a factor of safety of more than four, based on the elastic limit. Taking this demonstration in conjunction with the X-ray studies which indicate that there are no flaws which would tend to be aggravated by operating conditions, the status of the casting is fully determined.

Fig. 23 Radiograph of Exhaust-Nozzle Flaws, Slightly Reduced

The turbine casing, both top and bottom halves, was fully investigated except for certain sections which exceeded the thickness which can be penetrated by rays at the present time. Fortunately these very heavy sections are not subject to critical stresses and are therefore not a matter of serious concern. The top half of the casing was found to be an exceptionally fine piece of work. It is practically flawless. The bottom half of the casing (Fig. 21) is equally sound with the exception of the inlet and exhaust nozzles, which contain a certain amount of gassy metal associated with some dirt. (See. Figs. 22 and 23.)

The radiographs were carefully studied in conjunction with the working pressures and metal thicknesses of the various parts. No flaws were indicated which would tend to form cracks or leaks, or extend during service. The problem then resolved itself into a determination of the amount of weakening due to the flaws and the probable resultant factor of safety of the casting. In the high-pressure nozzle the working stresses are low and the flaws are so small that their effect is of no commercial importance. In the exhaust nozzle the flaws are in general of the same magnitude as those in the inlet nozzle, but a large gas pocket was discovered behind a heavy boss. This pocket was fully outlined by the X-ray photographs and its extent defined. It was found to have no serious effect on the strength of the casting owing to the thickness of metal at that point. It introduced a point of incipient leakage, however, which was very objectionable as the steam pressure on the exhaust of this turbine is some 360 lb. per sq. in. gage. To meet this condition a plan was worked out for drilling out and bushing the casting at the boss and welding the bushing into place. With this correction a hydrostatic-pressure test was applied in conjunction with extensometer measurements, and the strength of the casting was checked in about the same way as the governor-valve body.

This work is particularly interesting as demonstrating the ability of the X-rays to define the extent of flaws and save a casting which might otherwise have to be abandoned due to uncertainty as to its actual internal condition. It may be noted here that the turbine-casing halves are the heaviest castings ever examined by X-rays.

Conclusion

In all, some thirty castings were examined for the high-pressure steam installation at Weymouth. Out of these only five proved seriously defective; the remainder were for the most part of extremely high quality. Through the use of X-ray examinations it was possible to eliminate castings which would have been unequal to the service owing to flaws that were invisible from the surfaces, and to demonstrate with a reasonable degree of certainty the soundness and strength of the castings accepted. In this way the objectives laid out in the beginning of the examination were achieved and the cost of the work, if considered as an insurance charge, was fully justified.

The observations made form an excellent basis for a further study of the materials in this installation as affected by the conditions of service. The experience gained should be of value not only in the design of future installations but also in coöperating with the foundries in eliminating the flaws found to be characteristic of certain designs and methods of manufacture.

X-ray technique is now very effective, but its economic use is not yet fully developed. In presenting this paper it is hoped, therefore, that the work described may be of interest in solving similar power-station problems and may suggest a basis for future development.

Defects in Large Forgings

Some of the Common Defects Encountered and a Brief Explanation of Their Causes—Methods Used to Insure Uniform and Homogeneous Material

By J. FLETCHER HARPER,[1] MILWAUKEE, WIS.

THE object of this paper is not to imply that all large forgings are defective or in any way to condemn their use, but to point out to designing and operating engineers some of the places at which defects may be encountered.

It must always be borne in mind that the type of stress which exists in the part and the nature of the operating conditions determine in many cases the danger of a slight flaw or defect. In many cases the seriousness of flaws or defects cannot be accurately determined by laboratory means, and it is only after years of experience under actual operating conditions that one can disregard certain defects in certain types of equipment which must be the cause of rejection in other equipment.

The statement is often made that the materials of today are not as good as they were formerly. This is not true; they are infinitely better today, but the masses used, the speeds operated at, and the temperatures and pressures now found in modern apparatus were not even considered a few years ago. It is this new order of things which calls for greater uniformity and homogeneity of materials. Most engineering formulas are based on a uniform material, but steel makers and fabricators assert that no such material is possible, or made, in the strict meaning of the word, and the formulation of an estimate of the seriousness of any defect in a specific piece of apparatus therefore becomes a compromise between theory and practice.

In considering defects found in forgings, it is well to classify them under two heads: first, those inherent in the material; and second, those caused by the method of fabrication. It is very common to have both kinds present, and it is entirely possible that one may so mask or so accentuate the other as to make any definite conclusions difficult.

Material Defects

The most common defects inherent in the material or the ingot from which forgings are made, are:

1 Variations in composition
2 Piping and gas pockets
3 Cracks
4 Slag lines and "ghost lines."

Variations in Composition. In the manufacture of large forgings, large ingots, which in reality are only steel castings of the highest type, are required. Such castings will naturally have varying cooling rates, and it is a law of solutions—and steel is a solution—that the higher concentrations will solidify first. It is only natural, therefore, that the chemical composition will vary somewhat from the bottom to the top, and from the center to the outside, of the ingot.

This variation, if not excessive, is of no great importance. The slight variations in physical properties from one end to the other can usually be corrected by heat treatment of the forging; and it is the usual practice to test the forging midway between the center and the outside to get the average results.

However, any practice in which two heats of steel are utilized without the employment of a large mixing ladle, or in which two ladles of steel are poured without the use of a common runner box, should be frowned upon.

Piping and Gas Pockets. As stated before, an ingot is nothing more than a very special steel casting, and as such it is subject to many of the defects of steel castings.

The mold, in the best practice today, is made of special cast iron. The laws of freezing of metals cause the outside surface next to the mold to solidify first, and as more heat is absorbed by the mold this skin grows in thickness. This thickness grows more slowly as the metal solidifies, due to the increased mold temperature and the insulating effect of the skin, causing the center to remain molten for a considerable time.

This freezing action is accompanied by contraction which causes the molten metal in the center portion to decrease in height, giving the hollow, cone-shaped upper portion known as the "sink head" or "pipe." If the rate of solidification is not proper, the outer portions of the ingot, being rigid, will exert enormous stresses on this inner semi-solid material, causing tearing or extension of the pipe.

This tendency to tear is further increased due to the rejection of the impurities into the last material to solidify. This action is more fully explained under the discussion of "Cracks."

Ingots of proper design as to shape and cooling rates should have the pipe or shrink entirely confined to the upper portion. But if due to improper design, or if two heats or ladles of material are improperly used, or the pouring or cooling is stopped at any one point, the ingot can easily have piping throughout its length or in several places. The surfaces of these pipe cavities are usually oxidized, which prevents any possibility of welding in subsequent forging operations.

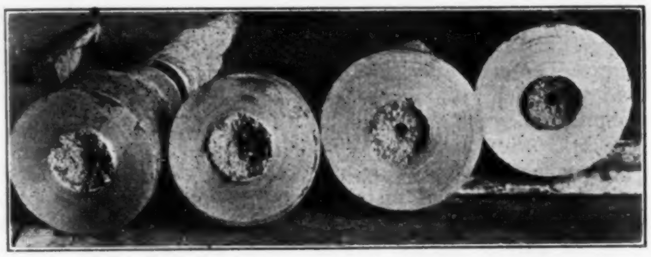

Fig. 1 Examples of Hidden Piping

The two forgings shown in Fig. 1, which have been cut in two, show examples of hidden pipe. In the case of both forgings the defects shown are due to secondary piping, for ample material had been cut from the top of the ingots to remove all normal shrinkage.

Gas pockets or blowholes are due to the rejection of gas by the molten steel at the time of solidification. If the solidification is normal, that is, progressing from the outside inward and from the bottom upward, the gas is carried into the sink head. But if the freezing takes place above molten metal and this gas collects, there will be a gas pocket which will cause trouble.

If considerable gas is present, a number of small bubbles will probably form just below the skin of the ingot and escape outward, leaving tiny "worm holes." The holes are usually oxidized and cause surface seams on forging or rolling. The extent of these seams are dependent on the depth of the gas "worm holes."

Cracks. If the surface of the ingot is not properly designed or the surface of the mold is rough or full of holes, natural contraction cannot take place and the ingot will crack.

Solidification begins about various centers which are at the lowest temperature, which results in the formation of crystal skeletons. These skeletons rapidly develop branches which become more and more coated with crystallizing matter until the whole resembles a tree or is, as it is termed, "dendritic."

In the case of an ingot the formation of a number of dendrites proceeds simultaneously from the chilled surface of the iron mold until they interlock and the whole material is solid. Impurities, having the lowest freezing temperature, will be carried in the mother liquid until final solidification, when they will be trapped between the dendritic branches.

If the dendritic formation proceeds from two surfaces it forces the non-metallics in the molten material to their extremities, until, when the dendrites interlock, a plane of inclusions is formed.

This plane of inclusions is a plane of weakness and can be the

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cause of a serious crack in an ingot and the forgings therefrom; and it is for this reason that the shape of the ingot mold, as regards surface, is designed so carefully, in order to obtain the maximum cooling surface with the minimum of corner segregation.

Slag Lines and Ghost Lines. "Ghost line" is a rather indefinite term applied to a frequently encountered defect. Ghost lines are streaks varying in composition from the major portion of the metal and usually containing slag impurities. They usually show up in the machined surface of the forging as light or dark marks, depending on the angle at which the light strikes the machined surface. As mentioned before, the material in these lines differs in composition from the rest of the steel, being usually very low in carbon and high in phosphorus. These lines differ in hardness from the surrounding material, which causes the tool to jump in machining and the lines to show. The depth of these marks is usually very small, so that with a very slight removal of material they disappear. However, when present they usually occur in many groups, and when one is removed, another appears.

Fig. 2 Ghost Lines in the Machined Surface of a Shaft

The danger from these lines is a much-debated question. It can be safely said that in straight tension the strength of the material containing the lines differs little, if at all, from that of adjacent material containing no lines. However, the action under reversed stress is another matter, and that under temperature changes appears to the author to be detrimental. Being of radically different composition, the expansion and contraction are different from what they are in the surrounding material. It is because of these two unknown variables, reversed stresses and temperature variations, that ghost lines are prohibited in high-class equipment.

Fig. 2 shows the machined surface of a shaft illustrating a bad condition of ghost lines.

Fabrication Defects

Defects due to fabrication may be classified under the following heads: 1, Laps; 2, Star cracks; 3, Clinks; 4, Improper reduction; 5, Heat treatment.

Laps. Laps are the folding over of the surface of the metal in the forging operation. This type of defect is usually due to working the metal too much in one direction before rotating it, or to the use of improper forging dies. It can also occur with proper working and die equipment if the shape of the ingot surface—the corrugations—is not correctly designed.

In large forgings this type of defect is usually not serious, as the amount of stock left to be taken off the rough forging in the machining operation is usually sufficient to remove all traces of the lap. However, the surfaces of a lap are covered with a scale which is folded under, and the lap may be so severe as to cause actual tearing of the metal. It is purely a case of bad forging practice and should be looked upon with suspicion, as other poor practices often accompany it when it is allowed to exist.

Star Cracks. Star cracks, so called from their most familiar shape, are another form of bad forging practice. They are formed in the center of a shaft and are usually not seen unless the shaft is bored. The common cause of this type of failure is forging after insufficient heating, that is, working the hot outer portion over the cold center and causing it to fracture.

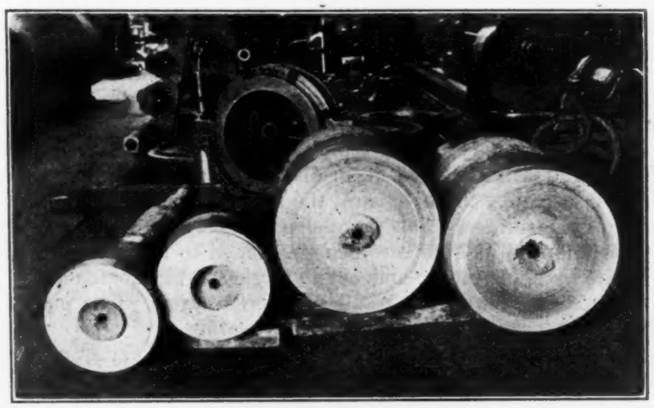

Fig. 3 Shafts Showing the Clink Type of Defect

Fig. 4 Fracture of Partially Forged Ingot as a Result of Internal Stress

Forging a large section on too small a hammer or press, or forging it down round instead of square as far as possible and then rounding it up, can also produce these defects.

Clinks. Clinks are one of the greatest possible dangers in the making of large forgings, and while they are not necessarily produced by bad practice, they are the result of not exercising proper care.

In the casting of large ingots or even small ingots of alloy steels, enormous stresses are set up in the cooling. If this cooling is allowed to extend below about 1000 deg. fahr. without being equalized, these stresses usually reach such a point as to cause rupture.

It is therefore considered good practice not to allow a large ingot, or the forging from it, to cool completely until it has been heated uniformly to above the critical temperature of the material.

It is obvious that it is often impossible to get the cycles of operations to come so that they will allow the completion of the forging before cooling. It is often necessary to ship ingots to other plants for the forging operation, but in all such cases they should be annealed to relieve the casting strains.

On reheating an ingot, the rate of heating until the center portion has passed the temperature of 1000 deg. fahr. should be very slow, otherwise the expansion of the outer portion will cause a clink.

The reheating of a forging which is partially forged and the equalizing of the temperature of the finished forging are operations which demand the greatest of care and experience if this class of defect is to be eliminated. The occurrence of clinks increases with the size of the work and the use of the denser alloy steels.

Fig. 3 shows two shafts which have been cut in two and which exhibit the clink type of defect. A comparison between the defects in this illustration and those of Fig. 1 clearly shows the different characteristics of these two types of defects. The defects due to pipe have a coarse-grained, heavily oxidized surface, while the clinks exhibit a clean rupture of solid metal.

Fig. 4 shows a piece of partially forged ingot which has ruptured. This ingot, which was 23 in. in diameter, was heated and forged to approximately 21 in. square; the ingot corrugation can still be seen at the corners. This piece of material cooled down and was set to one side with no care being exercised to relieve the strains set up by the heating and slight forging. Six months later it fractured as shown as a result of internal stress. The material was perfect, containing no flaw of any nature.

Improper Reduction. The major object in forging a piece of steel is to break up the grain size found in a steel casting and to increase the density and homogeneity of the material.

To accomplish this the original area of the ingot must be reduced. In order to gain the maximum advantage this reduction should be in a direction at right angles to that in which the maximum stress will be applied in the finished article. Furthermore, the physical tests made to determine the characteristics should be taken at a position to determine this condition of maximum stress.

Reduction causes the dendritic crystallization and the secondary crystallization to be elongated at right angles to the applied force. This produces what is commonly termed "fiber," and greatly increases the physical properties in the parallel direction but at considerable sacrifice to the transverse ductility.

It is for this reason that ring forgings are forged by expanding over a mandrel and tested tangentially. While it is impossible to work some material, such as turbo rotor shafts which are stressed and tested radially, by expansion, the Allis-Chalmers Company has found that by proper heat treatment a fairly large reduction, with its accompanying advantages, can be made with no sacrifice in strength or ductility in any direction.

Because of the fibering of the structure of forgings, care should be exercised that a change of dimension in the forging operation is made by a flow and not by a sharp cut-off. If the flow of material is not obtained a weakness at the points of changes in diameter is experienced.

Heat Treatment. Defects due to the heat treatment of forgings is one subject which would demand many pages for its consideration, even in very rough outline. However, there are several major points of caution which can well be mentioned.

Any heat treatment should be applied only after all forging operations have been completed.

The heating and cooling should be uniform and applied to the entire mass, eliminating all possibilities of local heating or cooling of any part.

In large forgings the effect of mass must be considered, and time must be allowed for the complete penetration of the heat. It should be appreciated that there is a certain amount of inertia present which resists structural changes, and that the larger the mass, the greater will be the length of time necessary to accomplish any change.

Any heat treatment that obtains high physical strengths but leaves the material in a highly stressed condition, should be avoided.

A uniform distribution of the microscopic constituents in as fine a size as possible should be the desire, in order to prevent cleavage planes of weakness.

The Allis-Chalmers Company has found that to secure good large forgings the following precautions must be taken, not on one or two forgings but on each and every forging.

The ingots used for making the forgings must be made under careful supervision as to material melted, method of melting, temperatures obtained, pouring conditions, and mechanical handling.

The forging operations are closely controlled as to the heating and forging. The forge department is apprised of the stresses under which the finished piece will operate, in order that it may get the maximum results attainable by reduction and heat treatment before making the forging.

The physical tests are so made as to be representative of the forging, and in such a manner as to check the operating stresses in the finished machine.

The heat treatment and chemical characteristics are checked by careful microscopic examination and analysis before the forging is released by the metallurgical department.

Fig. 5 Periscope Used for Examining the Bore of a Shaft

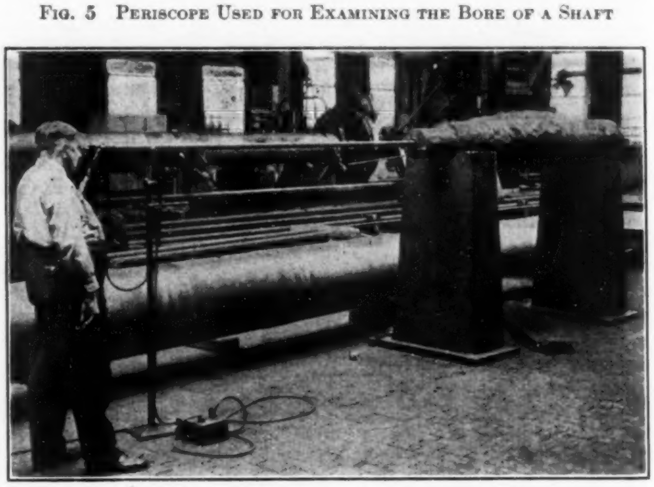

Fig. 6 Periscope of Fig. 5 in Use

All laps, cracks, seams, or surface defects are completely chipped out before the piece is machined. Great care is used to see that all traces of the defect are removed, even to the extent of etching and examining with the microscope. In defects of this kind there is great danger that the metal at the base of the visual crack will be found to be distorted or microscopically ruptured, and if such material were allowed in service, there would be risk of fatigue failure.

All shafts over 9 in. in diameter have an exploratory hole ($1^1/_2$ in. in diameter or larger) for use in periscopic examination.

There are several types of periscopes for this work, but the one which has been used with success for the past ten years is shown in Figs. 5 and 6.

This instrument consists of a brass tube, the inner end of which contains an electric light for illuminating the bore, and a reflecting prism. The outer end has a focusing telescope, the object of which is to bring the image up to the eye, and not to magnify it. This equipment allows the slightest flaws to be detected within the bore of the shaft.

It is believed that with the careful observations as outlined above, large forgings today offer the best means of securing homogeneous material. However, a full understanding of the nature of defects and their reference to operating stresses should be thoroughly understood by all operating and designing engineers. It is this neglect to realize the limitations of large forgings which has caused them, through failures, to fall into disrepute; while in reality they are today one of our most uniform materials of construction.

Formulas for Computing the Economies of Labor-Saving Equipment

By JAMES A. SHEPARD,[1] MONTOUR FALLS, N. Y., and GEORGE E. HAGEMANN,[2] NEW YORK, N. Y.

The engineer and manufacturer have heretofore been without correct and adequate means for measuring the relative economies of two or more industrial operations or installations of equipment. Proposed new apparatus might indicate a saving in manual labor, but this did not guarantee that it could be profitably substituted for machines or devices in use at the time. Such formulas as existed to determine this latter point were too complicated to be easily applied and generally used.

The present paper, following that of a year ago when the first engineering attack was made on the problem, develops five simple equations for determining the economies of an installation of labor-saving equipment. They show the maximum investment which will earn simple interest; the yearly cost to maintain the mechanical equipment ready for operation; the yearly profit, in excess of simple interest, from the operation of the equipment; the yearly profit from operation, in per cent on investment; and the years required for complete amortization of investment out of earnings. The method of applying these formulas, the evaluation of their various factors, and the correct assumption of bases, are explained in detail. The calculation of a labor-burden account, as distinct from the ordinary factory-burden account, and the transfer of certain items from the regular burden account to a special productive-labor-payroll account are recommended and explained. Standard forms to systematize investigations are worked out.

THE modern conception of engineering has broadened the engineer's field of activity to include responsibility for economic as well as technical achievements. It is essential, therefore, that dependable and convenient methods for economic research be furnished him; also that provision be made in our accounting systems for developing economic information to enable him to predict the results which will follow the adoption of his recommendations.

Periodic shortage of industrial labor, its rapidly increasing direct cost, and an indirect cost of considerable magnitude incidental to its employment under modern factory conditions, render accurate methods for analyzing its economic relation to mechanical aids and substitutes a matter of prime importance. Under the relatively simple organization of our industries a generation ago, comparative efficiency estimates, based upon the exercise of personal intuition or judgment, may have closely approximated reality. The relatively complex organizations which present-day conditions make essential usually render such crude processes of estimating inadequate and inaccurate.

A survey made for the purpose of finding out what current practice was followed in evaluating labor saved by improved organization or mechanical equipment, brought out the facts that:

1. There is in use no adequate or generally accepted method for estimating the comparative economic value of alternative industrial processes, or for evaluating labor saved.
2. Individual practice usually approximates one of two widely divergent methods. The one most frequently employed estimates the value of labor saved at its base or payroll rate, with no contingent addition. The other, more rarely used, but growing in favor because of the palpable inaccuracy of the first, estimates the value of labor saved at the payroll rate plus full factory burden. The range of variation in practice which has been observed between these two methods is as high as 500 per cent.

Common procedure having failed to produce any foundation for an adequate system of industrial economic analysis, it becomes necessary, in view of the obvious needs of the engineering profession and of industry, to build up a suitable system. As might be expected, there is not unanimity of opinion as to the requirements for such a system.

It is admitted that the basic principles involved have been identified previously, and that there are extant formulas which, when skillfully applied, are capable of solving the economic problems of both engineering and industry. Experience has proved, however, that it is impracticable for any except economic specialists to employ successfully the methods heretofore available. As a matter of fact, a generation, during which their necessity has been appreciated, has not brought them into practical use in industry to any great extent. While it is possible for the engineer to use them, it is improbable that he will in general do so.

Elements for Industrial Economic Research

The following elements are considered requisite in making up a system for industrial economic research adapted to the needs of the engineer:

1. Formulas adapted for integrating in a single equation the factors involved in usual industrial economic problems
2. Standardized values for all economic factors which are capable of standardization
3. Standardized methods for developing the values of economic factors which are variable
4. Standard forms to afford a uniform procedure in economic research, and to reduce the clerical work involved
5. Standard forms for summarizing economic data so as to constitute a uniform and thus comparable record.

The details of the system should show the entire process of analysis in a manner easily checked, corrected, or modified.

The System Recommended

The formulas reported to the Materials Handling Division by a Sub-Committee during the Spring Meeting at Montreal in 1923 possess advantages which led to their approval by the Committee for the following reasons:

1. They are so composed as to develop in five simple equations all facts usually required
2. Unlike other methods available, both debit and credit factors are utilized. Hence the formulas give results in terms of net performance
3. The factors employed generally represent a single element of value. They are composite only where, in current practice, familiar elements are combined and are closely related. Standardized values may therefore be readily and accurately applied
4. They combine flexibility with mathematical exactness in a degree not heretofore possible.

In their original form, in deference to established methods of cost accounting, the credit factor "T, yearly saving in fixed charges, operating charges or burden, in dollars," was made to cover indirect costs arising from the employment of both labor and mechanical equipment. It has been found desirable to separate this factor into two elements, as follows:

T_a = yearly saving in labor burden, in dollars

T_b = yearly fixed charges, in dollars, on mechanical equipment employed as a standard of comparison, or which will be displaced.

T_a therefore represents the difference in indirect cost of labor (labor burden) between the two processes which are under comparison.

T_b represents the aggregate value of $A + B + C + D$, expressed in dollars, applied to mechanical equipment which is being used as a standard of comparison or which will be displaced.

Formulas for Computing the Economies of Labor-Saving Equipment

The formulas for computing the economies of labor-saving equip-

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ment are presented for adoption in the following modified form:

Let:

Debit Factors

- A = percentage allowance on investment
- B = percentage allowance to provide for insurance, taxes, etc.
- C = percentage allowance to provide for upkeep
- D = percentage allowance to provide for depreciation and obsolescence
- E = yearly cost of power, supplies, and other items which are consumed, total in dollars

Credit Factors

- S = yearly saving in direct cost of labor, in dollars
- T_a = yearly saving in labor burden, in dollars
- T_b = yearly fixed charges, in dollars, on mechanical equipment employed as a standard of comparison or which will be displaced
- U = yearly saving or earning through increased production, in dollars

- X = percentage of year during which equipment will be operated
- I = initial cost of mechanical equipment
- K = unamortized value of equipment displaced, less its resale or scrap value

Results

- Z = maximum investment, in dollars, which will earn simple interest
- Y = yearly cost to maintain mechanical equipment ready for operation (fixed charges)
- V = yearly profit, in excess of simple interest, from operation of mechanical equipment
- P = yearly profit from operation, in per cent on investment
- H = years required for complete amortization of investment out of earnings.

Then

$$Z = \left[\frac{(S + T_a + U - E)X + T_b}{A + B + C + D}\right] - K \qquad [1]$$

$$Y = I(A + B + C + D) \qquad [2]$$

$$V = [(S + T_a + U - E)X + T_b] - [Y + (KA)] \qquad [3]$$

$$P = \frac{V}{I} + A \qquad [4]$$

$$H = \frac{100 \text{ per cent}}{P + D} \qquad [5]$$

Valuation for Debit Factors of the Formulas

The debit factors A, B, C, D, and E employed in the formulas are capable of having arbitrary valuations assigned to them when related to definite classes of materials handling or other mechanical equipment. The Committee is now engaged in standardizing these values. When this work is completed the use of these standards will avoid the employment of improvised, and consequently erratic, values, and will tend to make analyses, conducted according to the proposed system, of standard composition and hence truly comparable.

Valuation for Credit Factors of the Formulas

The credit factor "S, yearly saving in direct cost of labor, in dollars," must of course be developed by a detailed analysis of the processes under investigation. The hourly saving in labor, valued at the base or payroll rate, should be multiplied by 2400 working hours (300 eight-hour days) to develop the saving for a *full year*. This value, with other credit factors, becomes adjusted to the actual conditions when modified by the factor "X, percentage of the year during which the equipment will be operated."

The credit factor "T_a, yearly saving in labor burden, in dollars," as already explained, represents the difference in indirect cost of labor required by alternative processes. Details of the indirect expenditures which are elements of this factor are given later on in this paper.

The credit factor "T_b, yearly fixed charges, in dollars, on mechanical equipment employed as a standard of comparison, or which will be displaced," is the aggregate value $A + B + C + D$ expressed in dollars. The total of these factors appears in the formulas as a credit, opposed to the equivalent aggregate of the same factors applied to the alternative mechanical equipment as a debit, expressed in per cent.

Items Which Are Elements of T_a and T_b

In the employment of either labor or mechanical equipment under factory conditions there are two separate classes of expense, direct and indirect. Direct expenditures, as a rule, may be readily determined. Indirect expenses are more difficult to identify.

One manufacturer who has made a careful analysis of the indirect expenses incidental to the employment of factory labor for the year 1923, determines the average ratio of indirect expense to payroll, for his entire plant, at 58.6 per cent. Since the conditions in this factory were fairly representative of its class, it is evident that any system which evaluates labor, whether labor used or labor saved, at the base or payroll rate, with no addition for indirect expenses, results in substantial error.

In arriving at the cost of labor used it is now customary to add to the payroll rate, as overhead expense or burden, a percentage sufficient to cover all indirect expenses. In recognition of the error arising from a failure to make a suitable addition in the case of labor saved, some have adopted the practice of adding for labor saved an amount equal to that added for labor used. It is true that the cost of labor is substantially the same, whether it is labor used or saved. Hence if the overhead, or burden percentage, were composed exclusively of items which are incidental to the employment of labor, it would be, when added to the payroll rate, a true measure of the value of labor, whether used or saved.

Unfortunately for such a purpose, however, cost-accounting systems do not usually develop as burden an amount covering simply the indirect cost of labor, because of the equal necessity for prorating to product, in terms of percentage added to productive labor, the direct and indirect expenses of the factory equipment, as well as a variety of other expenses which can be thereby more accurately, or conveniently, distributed into the cost of product. As a consequence factory burden, as currently accounted, covers not only the indirect cost of labor but also taxes, insurance, depreciation, maintenance, and all other fixed charges against plant and equipment; the cost of power, heating, lighting, etc.; and the payroll pertaining to all labor classed as non-productive. Accordingly we have, by using present accounting methods for our purpose, two primary sources of error in the burden account when setting a value on labor saved:

1 The burden account is excessive as a measure of the indirect cost of labor, because it contains much that is irrelevant to labor costs

2 A portion of the productive labor has been classified as non-productive, and has been charged to the burden account instead of to the productive-payroll account; that is, the productive-labor account does not cover all of the labor which is truly productive.

As an expedient in accountancy it is entirely rational to classify as non-productive certain labor which is in fact productive. The work of yard men, truckmen, crane operators, and all others who handle materials cannot in some instances be charged directly to product. Hence such labor is properly classified as non-productive for accounting purposes, and is made a part of factory burden. It is irrational, however, to employ a factory burden thus composed as a measure of the incidental cost of labor. It is equally irrational merely because certain labor has been given a fictitious classification for accounting purposes, to give it a similar fictitious valuation in an efficiency study.

In a plant or department having a burden rate of 100 per cent a workman who receives 70 cents per hour cannot properly be said to cost \$1.40 per hour when operating an engine lathe upon product, and but 70 cents per hour when repairing this engine lathe. Charging the labor at the varying rates may produce accurate final results in accounting the cost of product, but it fails completely as a means for developing the true cost of the labor performed, or saved.

From the foregoing explanation it becomes clear that to meet the needs of the engineer in arriving at a value for labor saved by a revision in processes, or by improved mechanical equipment, a new factor must be developed by the cost accountant which shall

include all items of expense incidental to the employment of labor, and which shall exclude all items of the factory burden which are irrelevant to the employment of labor. It is suggested that the new factor be differentiated in name, as in composition, by calling it "Labor Burden."

As a practical illustration of the relation which labor burden may be expected to bear to factory burden, a comparison is given here, developed by a manufacturer according to the methods above suggested, and based upon the conditions prevailing in his plant for the year 1923.

$$\text{Factory burden} = \frac{\text{Total of factory-burden account}}{\text{Total of regular productive payroll}} = \frac{\$417{,}036.70}{\$280{,}585.05} = 148 \text{ per cent}$$

$$\text{Labor burden} = \frac{\text{Total of labor-burden account}}{\text{Total of special productive payroll}} = \frac{\$170{,}757.71}{\$290{,}947.51} = 58.6 \text{ per cent}$$

$$\text{Relative ratio} = \frac{\text{Labor burden}}{\text{Factory burden}} = 39.6 \text{ per cent}$$

The figures given are an average for the entire plant, and were developed for the purpose of showing the wide difference between factory burden and labor burden. Current practice in developing separate burden values for each department of the factory, while equally applicable in the case of the labor burden, is not considered equally necessary.

Factory burden may vary widely. Variations exceeding 400 per cent between departments of a factory or in different industries are not unusual, owing to the wide differences in the relation which fixed charges (such as taxes, insurance, depreciation, maintenance, etc., upon buildings, machinery, and tools) bear to the productive-labor payroll. Fixed charges upon plant represent an important element of factory burden, hence relatively high factory-burden rates follow when the relation of investment in plant and equipment to productive payroll is high. They are relatively low when the relative investment in plant and equipment to productive payroll is low.

The items of indirect expense which go to make up labor burden, being independent of the physical surroundings under which the labor is performed, and arising purely out of the organization and related factors necessary for the direction and control of labor, may be expected to remain fairly uniform under a given type of organization. Such differences as are to be expected would arise principally through a varying relation between the relative elaborateness of organization conventional in a given line of business, and the relative wage scale. Experience seems to indicate, however, that the more highly skilled and hence highly paid trades generally demand a more elaborate and hence more costly organization for their guidance, and that accordingly the *percentage* which labor burden bears to payroll may not be subject to much variation in correctly organized industries of a given class.

The development of the exact labor burden pertaining to an industry, or to any department of an industry, is a simple matter in case extreme exactness is desirable. Labor burden may be developed from the same accounting which develops factory burden, values of the items which are chosen to compose the labor burden being carried to an extra column so as to form a separate total.

An important difference in the functions performed by factory burden and labor burden should not be overlooked in choosing items which are to be included in the latter. Factory burden represents an average ratio which a certain class or group of expenditures bears to productive labor in making up the cost of a given product or service. Hence a high degree of exactness in reflecting actual factory conditions *at the time the work is done* is essential as a means of developing actual factory costs at that particular period. Labor burden also represents an average ratio which a restricted class or group of expenditures, incidental to the employment of labor, bears to productive labor. Since those items of expense are already elements of factory burden, they have no further significance in the accounting system except as a guide for the future in estimating the prospective cost of similar elements of expense, under modified conditions. Accordingly a high degree of present exactness is not essential, whereas the closest possible approximation to average conditions which may be expected *through a series of years* is desirable.

The common expedient of rejecting in the accounting an item of economy because it cannot be realized immediately, is not applicable in making up labor burden. The broad principle that, in the long run, incidental expenses will rise and fall proportionately with the productive payroll, becomes applicable.

Items Recommended for a Labor-Burden Account in the Metal Trades

When making up a labor-burden account, variations will be necessary to meet the requirements of different kinds of industries. The one here presented is fitted to the needs of the metal trades. The Materials Handling Committee will compile lists for other trades as rapidly as possible.

Entire Cost, with the exception of percentage assessed to non-productive departments:

- Factory supervision
- Foremen and assistants
- Employment department
- Factory accounting departments
- Factory stenographers and clerks
- Safety department
- Stores office
- Tool storage
- Production department, including all subdivisions
- Traffic department
- Employees taking inventory
- Extra compensation for overtime, etc. (if accounted as an item of burden)
- Watchmen, gatemen, and ushers
- Instruction to apprentices
- Cleaners, oilers, and porters
- Cleaning and miscellaneous work by productive workmen
- All other similar expenditures.

Factory supervision should not be construed to cover supervision of the drafting room when it is a factory department. Foremen and assistants in non-productive departments such as tool room, pattern shop, development work and plant-improvement work, should be excluded from the special burden account.

Entire Cost:

- Accident compensation insurance
- Sick benefit and employees' relief
- Employees' death benefit
- Shop vacation allowances
- Maintenance of hospital, cafeteria, club, and welfare activities
- Gratuities
- Defective work and other losses due to errors
- Complaints and correction of product
- Factory office supplies
- Miscellaneous factory supplies
- All other similar expenses.

Part Cost:

- Building rental
- Factory insurance
- Fire department
- Factory taxes
- Maintenance of land and factory buildings
- Factory depreciation.

In assessing the percentage of insurance, fire department, taxes, maintenance, and depreciation, that percentage of the total cost should be included in the labor burden which will represent the *proportion of the occupancy of the building by workmen* as compared to other types of occupancy.

Since the regular productive payrolls do not ordinarily cover all of the labor which contributes toward production, the following classes of labor, often accounted as non-productive as far as they are included in the regular burden account, should be transferred from the regular burden account to the special productive labor payroll:

Items Recommended to be Transferred from Regular Burden Account to Special Productive-Labor Payroll

Entire Payroll	Railway crews Materials-handling and miscellaneous labor Stores department materials-handling labor Auto truckers and helpers Inspectors Receiving and disbursing raw stock Crane and elevator operators Shipping department All other similar labor.

The following classes of labor, as far as they are included in the regular productive payroll, should be deducted in order to develop the special productive labor payroll:

Items Recommended to be Deducted From Regular Productive Payroll to Develop the Special Productive-Labor Payroll

Entire Payroll	Drafting room Tool room Pattern shop All development work All plant improvement work.

The percentage which the labor-burden total bears to the corrected or special productive-labor-payroll total will represent the labor burden in the form of a percentage to be added to all productive labor. This process will develop a general labor-burden percentage. Where the burden accounting is departmentalized, a similar process conducted for each department will develop the departmental labor burdens.

A method which has been found convenient for developing labor burden consists in providing additional columns on the analysis sheet so that items may be transferred, as far as desired, from the regular burden account to these extra columns to form the labor-burden account. The values for both accountings are thus developed in parallel. A specimen form for such work is given in Table 1.

Necessity for a Correct Assumption of Bases

Experience in the use of the formulas for computing the economies of labor-saving equipment indicates that a correct assumption of bases upon which an economic analysis is to be conducted is equally vital with the subsequent mathematical treatment. The following suggestions are offered as a guide to methods which have been found preferable.

1 The valuation for the factor I should cover the complete cost of mechanical equipment, including special tools, dies, jigs, or other special apparatus; also motive power, in case the motor or other driving agency is a part of or direct connected to the equipment; also cost of installation.

2 The proposed equipment (called No. 1 Equipment on the analysis form, Table 2) should be assumed to operate for as great a percentage of the standard year of 2400 hours (any other number of hours may be substituted) as conditions will justify.

The function of the factor X in the formulas is to separate time during which the equipment under analysis is in operation productively, and therefore profitably, from idle time during which it is under fixed expense but non-productive. Therefore X_1 should be assumed at the closest approximation to 100 per cent which will reflect actual conditions.

For instance, suppose that we are analyzing the comparative efficiency of a machine tool which is to operate upon an item of product not required in sufficient quantity to occupy the equipment full time for a standard year, but the machine is capable of operating upon other items of product also, at approximately equal efficiency. The problem may be solved most conveniently by arbitrarily considering the full range of jobs as one, and extending the operating time to a full year for the main work under analysis.

As an alternative which will eliminate all errors made in an approximation like the above, each of a group of operations, which will together occupy the machine for a full year, may be analyzed individually, with the value of X_1 developed for each separately. The analysis for each item of the product should then be conducted according to the formulas, except that the percentage representing the value of $(A + B + C + D)$ should first be multiplied by X_1, this product being employed in the equations. The total of all results will then represent the true efficiency for the year's operations.

TABLE 1 SEPARATION OF FACTORY BURDEN AND LABOR BURDEN

Indirect Manufacturing Expenses	Factory-Burden Account: Non-productive payroll (Col. No. 1)	Factory-Burden Account: Other expense (Col. No. 2)	Factory-Burden Account: Total regular burden (Col. No. 3)	Labor-Burden Account: Total labor burden (Col. No. 4)	Labor-Burden Account: Transferred to productive payroll (Col. No. 5)
General					
1 Supervision, cost, employment, production, watchmen, cleaners, overtime, stores office, etc.	$ 69,552.24	744.39	70,296.63	59,752.13	
2 Supplies, misc. expense, etc.	25.33	10,307.64	10,332.97	8,783.02	
3 Accident compensation, hospital, sick and death benefit		13,665.25	13,665.25	11,615.46	
4 Purchasing, receiving, unassignable, freight, express and cartage	6,890.64	1,878.78	8,769.42		
5 Telegraph, telephone, traveling, etc.		8,040.87	8,040.87		
6 Insurance, taxes, depreciation		9,809.76	9,809.76	3,269.94	
7 Maintenance	1,586.58	1,353.29	2,939.87	2,498.88	
8 Miscellaneous labor	736.11		736.11		736.11
Total	$ 78,790.90	$ 45,799.98	$124,590.88	$ 85,919.43	$ 736.11
Departmental Service					
1 Small tools, maintainance, and replacements to tools and jigs, etc.	13,608.61	18,100.87	31,709.48		
2 Auto truckers, helpers, stock room	12,440.89	3,109.95	15,550.85	3,109.95	12,440.89
3 Tool crib	7,284.26	72.51	7,356.77	7,356.77	
Total	$ 33,333.76	$ 21,283.33	$ 54,617.09	$ 10,466.72	$12,440.89
Power Plant					
1 Operating labor	6,682.14		6,682.14		
2 Fuel and other supplies		15,730.11	15,730.11		
3 Maintenance	905.41	983.50	1,888.91		
4 Insurance, taxes, depreciation		3,886.10	3,886.10		
Total	$ 7,587.55	$ 20,599.71	$ 28,187.26		
Direct Departmental Expense of Machine Shop, Assembly Shop, etc.					
1 Foremen, despatchers, cleaners, overtime	35,702.11	665.62	36,367.73	36,367.73	
2 Inspectors, laborers, stock, distribution, etc.	36,862.26	2,496.00	39,358.26	2,496.00	36,862.26
3 Defective work	745.45	18,595.19	19,340.64	19,340.64	
4 Defective purchased material and shop supplies		19,053.25	19,053.25		
5 Insurance, taxes, depreciation		39,556.33	39,556.33	13,458.58	
6 Maintenance, land and buildings, machinery, tools, patterns, etc.	17,647.86	6,084.77	23,732.63	2,708.61	
Total	$ 90,957.68	$ 86,451.16	$177,408.84	$ 74,371.56	$36,862.26

Direct Departmental Expense of Drafting Room, Tool Room and Pattern Shop					
1 Supervision, foremen and other labor.	22,506.75		22,506.75		
2 Supplies..........................		4,014.04	4,014.04		
3 Insurance, taxes, depreciation........		4,552.54	4,552.54		
4 Maintenance.......................	659.92	499.38	1,159.30		
Total..........................	$ 23,166.67	$ 9,065.96	$ 32,232.63		
Total Manufacturing Expense..........	$233,836.56	$183,200.14	$417,036.70	$170,757.71	$50,039.26
	Footing No. 1	Footing No. 2	Footing No. 3	Footing No. 4	Footing No. 5

DEVELOPMENT OF FACTORY BURDEN

Total of all factory payrolls..	$514,421.61
Less total of non-productive payroll, Footing No. 1..	233,836.56
Difference = regular productive-labor payroll = Footing No. 6................................	$280,585.05

$$\text{Factory Burden} = \frac{\text{Total of Factory-Burden Account, Footing No. 3}}{\text{Total of Regular Productive Payroll, Footing No. 6}} = \frac{\$417{,}036.70}{\$280{,}585.05} = 148 \text{ per cent}$$

DEVELOPMENT OF LABOR BURDEN

Regular productive payroll, Footing No. 6..	$280,585.05
Less drafting, tool, pattern and plant-improvement payrolls..................................	39,676.80
	$240,909.25
Plus items transferred to productive-labor payroll, Footing No. 5............................	50,039.26
Total of special productive-labor payroll, Footing No. 7.....................................	$290,947.51

$$\text{Labor Burden} = \frac{\text{Total of Labor-Burden Account, Footing No. 4}}{\text{Total of Special Productive Payroll, Footing No. 7}} = \frac{\$170{,}757.71}{\$290{,}947.51} = 58.6 \text{ per cent}$$

Ratio Labor Burden to Factory Burden = 39.6 per cent

TABLE 2 COMPARATIVE ECONOMIC ANALYSIS NO. 3

Showing values for Z, V, P, and H as per formulas recommended by A.S.M.E. Committee.

It is assumed that the use of No. 2 equipment is generally accepted practice, while No. 1 is under examination for comparative economic efficiency. The factor K should be given zero value unless No. 2 is in use and would therefore be displaced by No. 1 with a corresponding capital loss.

No. 1 (designated by subscript numeral 1): 1 Semi-Automatic Turret Lathe. Cost $6100; operating 2280 hours per year; requires 1 operator; hp. required, 5; cost of power, 3 cents per kw-hr; reduced occupancy of buildings valued at $115.

Operated for Equal Production in Comparison with

No. 2 (designated by subscript numeral 2): 2 Engine Lathes. Cost, $4800; operating 4320 hours per year; requires 2 operators; hp. required, 6; cost of power, 3 cents per kw-hr. This equipment is not in use.

Average Values. None.

DATA REQUIRED FOR ANALYSIS

No. 1 One Turret Lathe		1 year = 2400 hours		No. 2 Two Engine Lathes	
One		Number of units employed		Two	
$^*X_1 = 95\%$		Per cent of year employed	(X)	$^*X_2 = 90\%$	
$A_1 = 6\%$		Per cent on investment	(A)	$A_2 = 6\%$	
$B_1 = 3\%$		Per cent for insurance, etc.	(B)	$B_2 = 3\%$	
$C_1 = 5\%$		Per cent for upkeep	(C)	$C_2 = 5\%$	
$D_1 = 10\%$		Per cent for depreciation	(D)	$D_2 = 7.5\%$	
Total = 24%				Total = 21.5%	
E_1X_1 =	$ 250.00	Cost of power, etc.	(E)	E_2X_2 =	$ 284.00
2280 hr. at 60 cents	$1368.00	Cost of labor	(S)	4320 hr. at 70 cents	$3024.00
80% of payroll	$1094.40	Cost of labor burden	(T_a)	80% of payroll	$2419.20
$I_1(A_1+B_1+C_1+D_1)$ =	$1464.00	Cost of fixed charges	(T_b)	$I_2(A_2+B_2+C_2+D_2)$ =	$1032.00
Total for 95% of yr.	$4176.40	Cost of operation		Total for 90% of yr.	$6759.20
	115.00	Value of increased production	(U)		none
	$6100.00	Cost of equipment	(I)		$4800.00
		Unamortized value of equipment less resale value	(K)		$1320.00

VALUATION OF FACTORS

	$A_1 + B_1 + C_1 + D_1$		24 % = $A + B + C + D$
	$E_1 - E_2$ =	$ 250.00 — $ 284.00 =	— $ 34.00 = E
	$S_2 - S_1$ =	$3024.00 — $1368.00 =	$1656.00 = S
	$T_{a2} - T_{a1}$ =	$2419.20 — $1094.40 =	$1324.80 = T_a
	T_{b2}	=	$1032.00 = T_b
	$U_1 - U_2$ =	$ 115.00 — none =	$ 115.00 = U
[2]	$Y_1 = I_1(A_1 + B_1 + C_1 + D_1)$	=	$1464.00 = Y
	I_1	=	$6100.00 = I
	K_2	=	$1320.00 = K

* X is applied individually in Cases Nos. 1 and 2, hence 100 % = X

SOLUTIONS

Z = Maximum Investment Which Will Return Simple Interest on Investment

[1] $$Z = \left[\frac{(S + T_a + U - E)X + T_b}{A + B + C + D}\right] - K = \mathbf{\$17340.00}$$

V = Yearly Profit from Operation

[3] $$V = [(S + T_a + U - E)X + T_b] - [Y + (KA)] = \mathbf{\$2697.80}$$

If it is not found possible to make the group of operations cover a full standard year, then a correct result will be obtained by taking the factor $I_1(A + B + C + D)$, multiplying it by the percentage of a standard year during which the equipment is idle, and deducting the product from the above-named aggregate efficiency.

The factor X_2 should represent the percentage of a standard year during which the equipment to be displaced (No. 2 Equipment in Table 2) would produce an output equal to the proposed new equipment (No. 1 Equipment in Table 2), not, however, exceeding 100 per cent unless operated during a day-and-night run. For day-and-night running the maximum will be 200 per cent, beyond which two or more No. 2 (displaced) Equipments must be assumed. If not operated during a night run, for percentages above 100 it will be necessary to assume two or more No. 2 (displaced) Equipments.

For day-and-night operation it is usual to make the valuation for the factors C and D 150 per cent of that employed for a day run only.

3 The credit factor "U, yearly saving or earning through increased production, in dollars," in the sense contemplated by the formulas is the valuation, actual or potential, where an increase in production is or will be required and the usual expedient of extending the plant and employing more workmen is thereby avoided.

As an illustration: Two alternative processes show about equal efficiency on the usual comparative basis of equal production. One equipment, however, will be occupied 90 per cent of the time for required production. The other produces the necessary volume of product operating only 60 per cent of the time. Even though not needed at once, the potential extra productive capacity of the second equipment to meet unexpected demand has a certain money value as an insurance of ample product. If the extra productivity can be utilized, and an extra equipment and operator, with incidental building floor space, heating, lighting, etc. are thereby made unnecessary, a very much higher money value for increased production becomes appropriate.

In those cases where a strictly limited amount of product is required, and there are no accessory conditions which serve to give a potential or actual value to increased production, it may be necessary to give U a zero value.

P = Yearly Profit in Per Cent on Investment

[4] $$P = \frac{V}{I} + A = \textbf{50.2 per cent}$$

H = Years for Complete Amortization of Investment Out of Profits

[5] $$H = \frac{100\%}{P + D} = \textbf{1.66 years}$$

TABLE 3 SUMMARY OF ANALYSIS

Estimated actual investment required for No. 1	$6100.00
Estimated excess investment in No. 1 over No. 2, $I_1 - I_2$, or I_1	$1300.00
Estimated yearly profit from operation No. 1 over No. 2, excess above simple interest	$2697.80
Estimated value of reduced labor turnover	.
Total	$2697.80
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on investment, total	50.2 %
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on excess investment, $\frac{I_1}{I_1 - I_2} P$, total	235%
Estimated time required to amortize entire cost of No. 1 out of earnings in excess of No. 2	1.66 years
Estimated time required to amortize excess cost of No. 1 over No. 2 out of earnings in excess of No. 2, $\frac{H}{\frac{I_1}{I_1 - I_2}}$	0.33 year

Standard Form to Afford Uniform Procedure in Conducting Economic Researches

As a convenience to the engineer in conducting economic researches, to afford a readily readable record of the assumptions and processes employed, to standardize the work and results so that they will be comparable with similar researches, to guide the research along correct lines, avoiding oversight or error, and to save time, the form for comparative economic analyses shown in Table 2 is submitted.

Standard Form for Summarizing Economic Data

The summary of an economic research shown in Table 3 reviews the factors which have an economic value, such as:

1 Estimated capital required
2 Estimated yearly profit over alternative
3 Estimated profit in per cent on investment
4 Estimated time required to amortize investment
5 Estimated saving through reduction in labor turnover.

It should also include practical considerations which may have no immediate money value, but which may nevertheless provide the ultimate weight of evidence for or against a given choice, such as:

6 Estimated relative flexibility to adapt to unforeseen conditions or types of product
7 Estimated relative continuity of service through relative durability, inherent reliability, or because of labor conditions.

The formulas and analyses above presented furnish the engineer with a ready and accurate device by which he can measure the economies of present and proposed operating methods and equipment, and decide correctly and with certainty between alternative proposals.

An Application of the Formulas for Computing Economies of Labor-Saving Equipment

BY GEORGE LANGFORD, JR.,[1] CHICAGO, ILL.

In this paper the A.S.M.E. Materials Handling Division's formulas for computing the economies of labor-saving equipment are applied to the purchase and operation of an electric industrial truck in place of hand lift trucks. The type of work done by the electric truck is described, and this description is followed by an analysis of the saving its adoption effected and a detailed explanation of the practical features involved in the evaluation of the various factors used by the formulas, together with a statement of the conclusions arrived at and of features beyond the scope of the formulas.

At THE Spring Meeting of the A.S.M.E. held at Montreal, Canada, May 28 to 31, 1923, and in MECHANICAL ENGINEERING for September, 1923, the Materials Handling Division of the Society submitted a group of formulas for computing the economies of labor-saving equipment. A number of formulas accomplishing the same results were then in existence, but were so cumbersome and required so much knowledge of the subject of economics that they were utterly unfitted for the practical use of the average engineer.

The formulas evolved by the Materials Handling Division are designedly of extremely simple form and are very easily applied where there is a difference in labor by a new method as compared with an older method, whether it be some method or process, a material-handling device, or a machine tool.

Hypothetical analyses using these formulas have been published several times before, but while these are both interesting and instructive, an analysis of a practical application of these formulas may perhaps be of more positive value.

In December, 1924, the Belden Manufacturing Company of Chicago, Illinois, bought a type R-1 Wright-Hibbard elevating platform truck for use in their wire-drawing plant and magnet-wire plant. This truck (Fig. 1) was bought to take the place of several hand lift-truck operations and augment several others, and has been in continuous operation for the past three months. This electric industrial truck has a rated capacity of 2000 lb. with a weight of 1395 lb., which makes it especially convenient in plants having elevators of small capacity. It has a loaded speed of $4^1/_2$ miles per hour and an empty speed of 6 miles per hour, both being a great deal faster than a workman will walk. For motive power it uses a 2-hp. 12-volt d.c. motor operating from either an Edison or lead battery of surprisingly small size. The charging equipment consists merely of a small-sized Hettner motor-generator set with a rheostat and voltmeter and ammeter, and generally has the battery on charge the better part of the night.

The truck is set to a great variety of uses. In the first place, it carries all of the copper rod used in the rod mill from the stock room in loads of from 1600 to 1800 lb. over a rough plank floor, and then over approximately 150 yd. of winding concrete aisles. It carries all of the coils of intermediate sizes of wire from the intermediate wire-drawing machines to the fine wire-drawing machines on lift trucks loaded with about 2000 lb. of copper wire—a run of 25 yd. over concrete. It carries all of the stranded wire used in the magnet-wire plant from the stranding department, which means a carry of about 175 yd. over concrete to the elevator, and then up on the elevator to the third floor. These loads will run up as high as 1500 lb. It carries a great deal of the finished magnet wire from the third floor to the second-floor stock room in loads of 1000 lb. or so. It carries large loads of empty spool trays much faster than can be done by hand lift trucks. It carries also large loads of packed cases of wire on spools from the various departments to the shipping department in loads up to 2000 lb. In short, it does all that was done with hand labor and the lift trucks, and more besides, the hand lift trucks being used almost exclusively now for short hauls and intradepartmental work.

It is not intended to explain the theory of the formulas or of their components, the Committee already having done that, but

[1] Belden Manufacturing Company.

Contributed by the Materials Handling Division for presentation at the Spring Meeting, Milwaukee, Wis., May 18 to 21, 1925, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. All papers are subject to revision.

it would be well to look into the practical resolution of the various components comprising the detailed analysis.

The cost of the truck was taken as the sum of its net cost, amounting to $1724.80; the net cost of the charging equipment, $348.97; the freight on these two items, $23.78; and the labor and supplies necessary for installation, $45.00; the total being $2142.55.

In the formulas the working year is taken as 300 days of 8 hr. each, but in all the departments of the Belden Manufacturing Company in which the truck is in operation, the working day is longer than that, which, when idle time is also taken into account, brings the working year up to approximately 2500 hr. The number of working hours in a year has really no effect on the operation of these formulas as they are relative to each other, power being reckoned for the year as a whole, and the various factors, such as

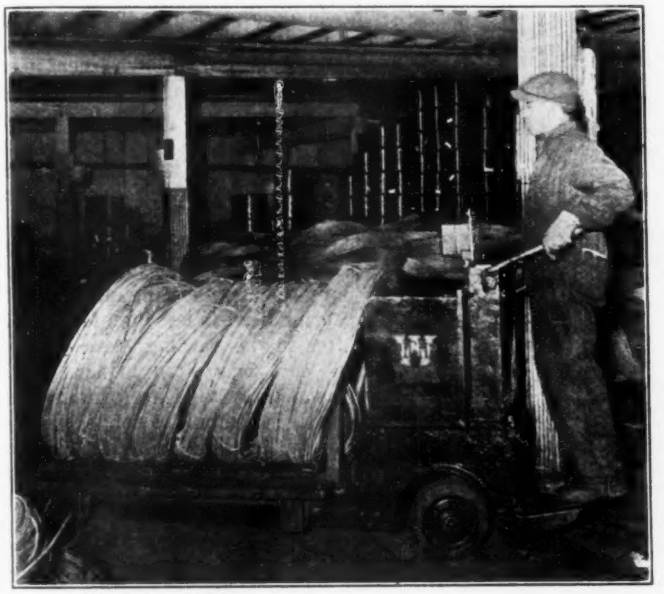

Fig. 1 Electric Truck Handling Skid of 8 Rolls of Pickled Copper Rod Weighing About 215 Lb. Each

allowance on the investment, insurance, etc. being percentages on the total cost.

Six per cent was taken as the allowance on the investment, that being standard practice, and in like manner 4 per cent was assumed sufficient to cover the cost of insurance, etc.

In estimating the percentage of the working year that the units are in operation, the fact that the no-load time of the electric truck is less than the no-load time of the hand lift trucks accounts for the difference between 90 per cent and 80 per cent.

In figuring the percentage upkeep, care was taken to have all of the items higher than will probably be the actual case, for as the truck grows older the maintenance will undoubtedly be higher, and by setting a high average figure the results will be well on the safe side. Thirty dollars is ample to cover the cost of oil and grease per year, a Ford car using less than twice that amount. Fifteen dollars should provide plenty of distilled water and all of the acid that may slop out. A new set of tires costs approximately $30 and it is assumed that they will last a year in their present service. The daily repairs amount chiefly to testing the battery and adding water, and allowing half an hour per day for that at 55 cents, will amount to $84 per year. General repairs should be generously provided for by 10 per cent of total cost allowance, or $214.25. According to the manufacturers of the Exide battery the average life of one of their batteries in industrial-truck service is three years, and so the battery depreciation will amount to one-third of the installed cost of $175, or $58.33 per year. The sum total of these upkeep charges amounts to $431.58, or very close to 20 per cent on the total investment.

In figuring the depreciation charges as 17 per cent on the investment, the life of the truck was assumed to be six years. It is possible that it will last longer than that, but six years is on the safe side and carries the weight of authority.

The battery requires approximately 12 kw-hr. of current per night, current costing 1.4 cents per kw-hr., and as the small Hettner motor-generator set has a total efficiency of around 75 per cent, the power bill will run up to $67.20 per year.

The Wright-Hibbard truck requires but one operator, who does all of the driving of the truck and all of his own loading and unloading except in very isolated instances, in which cases other operators may lend him a hand in a spare moment. According to the best information obtainable, the truck takes the place of the labor of between 2.5 and 3.0 men, so again to be on the safe side, 2.5 is taken as the number of men the truck replaces. These hand-lift-truck men were paid 48 cents per hour, which for all of them amounts to $3330 per year. The electric-truck operator is paid 50 cents per hour, and his yearly pay amounts to $1387.50. In addition there is the labor of the night electrician, who spends approximately half an hour per night putting the truck on charge and seeing that it is charging properly, and this amounts to $82.50 per year, which brings the truck labor up to $1470 per year.

No accurate figures were available for use in calculating the labor burden, but good authority at the plant puts it at approximately 75 per cent of the payroll. In the case of hand labor this will amount to $2497.50 per year, and for the electric truck it will be $1105.50.

In the formulas the total fixed charges include the maintenance costs, so that the total fixed charges on the truck investment amount to 47 per cent on the total cost, or $1007 per year. The fixed charges on the hand labor will of course be nothing, no capital being involved.

It may be well to digress a trifle and explain that the hand lift trucks are really not actually displaced by the electric truck. It had been planned for some time previous to the actual purchase of the truck to acquire possession of one, the problem being to select a type from the many different makes on the market. With that end in view, when new hand lift trucks become necessary they were not purchased, with the result that the electric truck merely takes the place of some imaginary hand lift trucks and augments the ones actually in use. Thus it cannot properly be said that this replacement of imaginary equipment will have cost the company money, and so the unamortized value of the replaced equipment less resale value becomes zero. Inasmuch as the hand lift trucks are in use in both the cases under consideration, their debits and credits will cancel each other and not enter into the comparison at all, and so are left out of the calculations entirely.

The total cost of operation in the case of the electric truck will be the sum of the labor cost of $1470, the labor burden of $1105.50, the power cost of $67.20, and the total fixed charges of $1007, or $3649.70 per year. The total cost of operation in the case of the hand labor is the labor at $3330 and the labor burden at $2497.50, or $5827.50 per year.

It would be next to impossible to figure the value of the increased production of one method over the other, but the electric truck does reduce the labor turnover by 60 per cent, which is admittedly to the electric truck's credit. What this would amount to is probably not worth the time required to figure it out. The value of increased production is set at zero in each case.

The evaluation of the various factors in the analysis is simple and exactly as shown in the detailed analysis.

In solving for the maximum investment which will return simple interest on the investment, the electric truck has credit factors of $1860 for labor, $1392 for labor burden, nothing for either the fixed charges on the hand labor or the value of the increased production of the electric truck over hand labor, and a debit factor of $67.20 for the increased cost of power of the electric truck over hand labor. These factors are algebraically added, divided by the total of the fixed charges for the electric truck, or 47 per cent, and then the unamortized value of the hand equipment, which in this case amounts to zero, is subtracted. The maximum investment which will return simple interest on the investment, or the maximum allowable investment, will then be $6776.17, or approximately three times what was actually paid for the truck.

In figuring the yearly profit from the operation of the electric truck, the same credit and debit figures as before are totaled, and then have subtracted from them the total cost of the fixed charges on the truck and 6 per cent on the unamortized value of the replaced hand-lift-truck equipment; this yearly profit resulting from the

COMPARATIVE ECONOMIC ANALYSIS NO. 3

Showing values for Z, V, P, and H as per formulas recommended by A.S.M.E. Committee.

It is assumed that the use of No. 2 equipment is generally accepted practice, while No. 1 is under examination for comparative economic efficiency. The factor K should be given a zero value unless No. 2 is in use, and would therefore be displaced by No. 1 with a corresponding capital loss.

No. 1 (designated by subscript numeral 1): Wright-Hibbard Electric Industrial Truck. Cost, \$2142.55; operating 2500 hours per year; requires 1 operator; hp. required, 2; cost of power, 1.4 cents per kw-hr.

Operated for Equal Production in Comparison with

No. 2 (designated by subscript numeral 2): Hand Labor. Cost, none; operating 2500 hours per year; requires 2.5 operators; hp. required, none; cost of power, none; This equipment recently in use.

Average Values. None.

DATA REQUIRED FOR ANALYSIS

No. 1		1 year = 2400 hours		No. 2	
One		Number of units employed		2.5	
*X_1 = 90%		Per cent of year employed	(X)	*X_2 = 80%	
A_1 = 6%		Per cent on investment	(A)	A_2 = 0%	
B_1 = 4%		Per cent for insurance, etc.	(B)	B_2 = 0%	
C_1 = 20%		Per cent for upkeep	(C)	C_2 = 0%	
D_1 = 17%		Per cent for depreciation	(D)	D_2 = 0%	
Total = 47%				Total = 0%	
E_1X_1 =	\$ 67.20	Cost of power, etc.	(E)	E_2X_2 =	\$ 0.00
... hr. at...	\$1470.00	Cost of labor	(S)	... hr. at...	\$3330.00
75% of payroll	\$1105.50	Cost of labor burden	(T_a)	75% of payroll	\$2497.50
$I_1(A_1+B_1+C_1+D_1)$ =	\$1007.00	Cost of fixed charges	(T_b)	$I_2(A_2+B_2+C_2+D_2)$ =	\$ 0.00
Total for 104% of yr.	\$3649.70	Cost of operation		Total for 104% of yr.	\$5827.50
	0.00	Value of increased production	(U)		0.00
	\$2142.55	Cost of equipment	(I)		\$ 0.00
		Unamortized value of equipment less resale value	(K)		\$ 0.00

VALUATION OF FACTORS

	$A_1 + B_1 + C_1 + D_1$		= 47 % = $A + B + C + D$
	$E_1 - E_2$	\$ 67.20 — \$ 0.00	= \$ 67.20 = E
	$S_2 - S_1$	\$3330.00 — \$1470.00	= \$1860.00 = S
	$T_{a2} - T_{a1}$	\$2497.50 — \$1105.50	= \$1392.00 = T_a
	T_{b2}		= \$ 0.00 = T_b
	$U_1 - U_2$	\$ 0.00 — \$ 0.00	= \$ 0.00 = U
[2]	$Y_1 = I_1(A_1 + B_1 + C_1 + D_1)$		= \$1007.00 = Y
	I_1		= \$2142.55 = I
	K_2		= \$ 0.00 = K

*X is applied individually in Cases Nos. 1 and 2, hence 100 % = X

SOLUTIONS

Z = Maximum Investment Which Will Return Simple Interest on Investment

[1] $$Z = \left[\frac{(S + T_a + U - E)X + T_b}{A + B + C + D}\right] - K = \mathbf{\$6776.17}$$

V = Yearly Profit from Operation

[3] $$V = [(S + T_a + U - E)X + T_b] - [Y + (KA)] = \mathbf{\$2177.80}$$

P = Yearly Profit in Per Cent on Investment

[4] $$P = \frac{V}{I_1} + A_1 = \mathbf{107.6\ per\ cent}$$

H = Years for Complete Amortization of Investment out of Profits

[5] $$H = \frac{100\%}{P + D_1} = \mathbf{0.803\ year}$$

operation of the electric truck over the hand lift trucks amounting to \$2177.80 per year, or more than the total cost of one truck.

The yearly profit in percentage on the investment is figured by dividing the yearly profit from the operation of the truck by the initial investment in the equipment, and adding to this the investment charges in per cent. This will then amount to 107.6 per cent yearly. The investment charge of 6 per cent is added to the per cent profit because in the debit factors evaluated in the previous equations the 6 per cent on the investment was deducted. In order to get the total or true percentage of profit it is necessary to add this 6 per cent. As the 6 per cent was subtracted in the one case and added in the other, the resultant will be zero, and the true percentage profit will really be the profit in dollars divided by the original investment.

To find the number of years for the complete amortization of the investment out of profits, 100 per cent is divided by the yearly profit on the investment in per cent plus the percentage depreciation on the investment, and amounts to 0.803 year, or a little less than ten months. That is, the machine will completely pay for itself out of profits in less than ten months of operation.

The results obtained from the use of these formulas are most interesting, and especially the fact that the electric truck will pay for itself in less than ten months and after that is earning more than its origina' cost every ten months. The formulas do not take into consideration the relative flexibilit'es of these two methods of handling materials, but inasmuch as the small electric truck will go practically wherever a hand lift truck can be pulled, and in addition will carry more than twice as much as a man can handle on a hand lift truck, the electric truck may rightfully be said to be the more flexible in operation of the two. In addition, the electric truck is efficient and well adapted for use on long, heavy hauls, where a hand lift truck would be almost impossible to use. The maximum speed of the loaded truck is about 4.5 miles per hour, which is a great deal faster than any man could be induced to pull a loaded hand lift truck.

This truck to date had been eminently satisfactory, barring one or two minor difficulties which have since been corrected, and while it is to be regretted that it has not been in operation long enough to provide a more accurate set of results and eliminate more of the estimations used, it is believed that the formulas fulfill extremely well the functions for which they were designed, and are of very great value in showing the relative value of the electric truck over the hand labor it replaces.

SUMMARY OF ANALYSIS NO. 3

Estimated actual investment required for No. 1	\$2142.55
Estimated excess investment in No. 1 over No. 2, $I_1 - I_2$, or I_1	\$2142.55
Estimated yearly profit from operation No. 1 over No. 2, excess above simple interest	\$2177.80
Estimated value of reduced labor turnover	
Total	\$2177.80
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on investment, total	107.6%
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on excess investment $\frac{I_1}{I_1 - I_2} P$, total	107.6%
Estimated time required to amortize entire cost of No. 1 out of earnings in excess of No. 2	0.803 year
Estimated time required to amortize excess cost of No. 1 over No. 2 out of earnings in excess of No. 2, $\dfrac{H}{\frac{I_1}{I_1 - I_2}}$	0.803 year

Remarks Covering Relative Flexibility, Safety, Durability, also Recommendation:

1 The electric truck is the more flexible of the two.
2 The electric truck is possibly the safer of the two as regards operation.
3 The electric truck is less durable than the hand lift trucks.
4 It is recommended that the electric truck be used.

Economic Efficiency of the Full-Automatic Turret Lathe in Comparison with the Semi-Turret Lathe

By R. J. WADD,[1] MONTOUR FALLS, N. Y.

This paper deals with the economic results arising from changes in machine-tool equipment as affected by the labor employed and the efficiency of production. Specific comparisons are instituted which are based on the work done by the full-automatic turret lathe and the semi-automatic turret lathe as analyzed with the aid of the recommended formulas developed by the Formulas Committee of the A.S.M.E. Materials Handling Division.

IN CONNECTION with the work that has been done by the Formulas Committee of the A.S.M.E. Materials Handling Division in developing formulas for computing the economies of labor-saving equipment, it may be of interest to examine the results of the comparison as applied by the recommended formulas to possible changes in machine-tool equipment.

Several years ago (1919), in bringing out a line of lighter-capacity hoists than it had ever manufactured, the company with which the author is associated was faced with the problem of increased production and shop costs lower than had been found possible in any article that it had previously produced. Anticipated sales requirements called for the running of larger-sized lots through the shop, which opened up the possibilities of changes in machine-tool equipment to obtain the increased production and decreased shop cost.

One of the economic changes made was from the semi-automatic turret lathe, employing one power-fed cutting position per operation, to the full-automatic type turret lathe with one or more power-driven cutting positions per operation on parts that would allow tooling for the cutting of more than one tool per operation; the former requiring an individual operator per machine, while with the latter it would be possible to group two or more machines around one operator. Before the required number of automatics and their tool equipment could be installed it was necessary to produce some of the parts on semi-automatic turret lathes. These lathes were practically new machines and all calculations are based on their originial investment charge. As the parts were swung over to the automatic turrets for production, actual costs of identical parts on the two types of machines became available. In the analyses under consideration the parts operated on were given the best possible conditions of manufacture on the two types of machines as regarded feeds, speeds, and tool equipment, and were equally applicable to the different machines under different conditions of quantity production.

Machining Winding Drums of Hoists. The winding drum of a one-ton hoist offered a comparative analysis of a full-automatic turret lathe and a semi-automatic turret lathe tooled to give practically equal production capacity. The drum required a finish over all on the barrel and on the flange at either end, and the hubs at either end were bored, counterbored, faced, and reamed. Two chucking operations were necessary per piece on either machine. The greater part of machining time was consumed in the finish of the barrel, which gave the semi-automatic turret lathe a slight advantage on production over the full-automatic turret on account of the heavier feeds and higher speeds allowable on the former machine. The full-automatic was required to operate continuously for the necessary production with from one to three cutting tools in position per operation, using one machine operator for two units, the second machine working on a

COMPARATIVE ECONOMIC ANALYSIS NO. 7

Showing values for Z, V, P, and H as per formulas recommended by A.S.M.E. Committee.

It is assumed that the use of equipment No. 2 is generally accepted practice, while No. 1 is under examination for comparative economic efficiency. The factor K should be given zero value unless No. 2 is in use and would therefore be displaced by No. 1 with a corresponding capital loss.

No. 1 (designated by subscript numeral 1): Full-Automatic Turret Lathe. Cost, \$3450; operating 2400 hours per year; requires 1/2 operator's time; hp. required, 5; cost of power, 5 cents per kw-hr; one operator for two machines.

Operated for Equal Production in Comparison with

No. 2 (designated by subscript numeral 2): Semi-Automatic Turret Lathe. Cost, \$3800; operating 2200 hours per year; requires 1 operator; hp. required, 4; cost of power, 5 cents per kw-hr. This equipment is not in use on this class of work, but was not discarded as plant equipment.

Average Values. Comparison based on lot of 3000 Class I hoist winding drums.

DATA REQUIRED FOR ANALYSIS

No. 1 Full Automatic		1 year = 2400 hours		No. 2 Semi-Automatic	
One		Number of units employed		One	
$^*X_1$ = 100%		Per cent of year employed	(X)	$^*X_2$ = 92 %	
A_1 = 6%		Per cent on investment	(A)	A_2 = 5.5%	
B_1 = 1%		Per cent for insurance, etc.	(B)	B_2 = 0.9%	
C_1 = 5%		Per cent for upkeep	(C)	C_2 = 4.6%	
D_1 = 10%		Per cent for depreciation	(D)	D^2 = 9.2%	
Total = 22%				Total = 20.2%	
E_1X_1 =	\$ 450.00	Cost of power, etc.	(E)	E_2X_2 =	\$ 330.00
2400 hr. at 40 cents	\$ 960.00	Cost of labor	(S)	2200 hr. at 75 cents	\$1650.00
59% of payroll	\$ 566.40	Cost of labor burden	(T_a)	59% of payroll	\$ 973.50
$I_1(A_1+B_1+C_1+D_1)$ =	\$ 759.00	Cost of fixed charges	(T_b)	$I_2(A_2+B_2+C_2+D_2)$ =	\$ 767.60
Total for 100% of yr.	\$2735.40	Cost of operation		Total for 92% of yr.	\$3721.10
	\$ 0.00	Value of increased production	(U)		\$ 0.00
	\$3450.00	Cost of equipment	(I)		\$3800.00
		Unamortized value of equipment less resale value	(K)		\$ 0.00

VALUATION OF FACTORS

	$A_1 + B_1 + C_1 + D_1$		=	22 %	= $A + B + C + D$
	$E_1 - E_2$	\$ 450.00 — \$ 330.00	=	\$ 120.00	= E
	$S_2 - S_1$	\$1650.00 — \$ 960.00	=	\$ 690.00	= S
	$T_{a2} - T_{a1}$	\$ 973.50 — \$ 566.40	=	\$ 407.10	= T_a
	T_{b2}		=	\$ 767.60	= T_b
	$U_1 - U_2$	\$ 0.00 — \$ 0.00	=	\$ 0.00	= U
[2]	$Y_1 = I_1(A_1 + B_1 + C_1 + D_1)$		=	\$ 759.00	= Y
	I_1		=	\$3450.00	= I
	K_2		=	\$ 0.00	= K

* X is applied individually in Cases Nos. 1 and 2, hence 100 % = X

SOLUTIONS

Z = Maximum Investment Which Will Return Simple Interest on Investment

$$Z = \left[\frac{(S + T_a + U - E)X + T_b}{A + B + C + D}\right] - K = \mathbf{\$7930.45} \qquad [1]$$

V = Yearly Profit from Operation

$$V = [(S + T_a + U - E)X + T_b] - [Y + (KA)] = \mathbf{\$985.70} \qquad [3]$$

P = Yearly Profit in Per Cent on Investment

$$P = \frac{V}{I} + A = \mathbf{34.5\ per\ cent} \qquad [4]$$

H = Years for Complete Amortization of Investment out of Profits

$$H = \frac{100\%}{P + D} = \mathbf{2.24\ years} \qquad [5]$$

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[1] Ch. Engr., Shepard Elec. Crane & Hoist Co. Mem. A.S.M.E.

Contributed by the Materials Handling Division for presentation at the Spring Meeting, Milwaukee, Wis., May 18 to 21, 1925, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. All papers are subject to revision.

COMPARATIVE ECONOMIC ANALYSIS NO. 8

Showing values for Z, V, P, and H as per formulas recommended by A.S.M.E. Committee.

It is assumed that the use of equipment No. 2 is generally accepted practice, while No. 1 is under examination for comparative economic efficiency. The factor K should be given zero value unless No. 2 is in use and would therefore be displaced by No. 1 with a corresponding capital loss.

No. 1 (designated by subscript numeral 1): Full-Automatic Turret Lathe. Cost, $3350; operating 2400 hours per year; requires 1/2 operator's time; hp. required, 4; cost of power, 5 cents per kw-hr.

Operated for Equal Production in Comparison with

No. 2 (designated by subscript numeral 2): Semi-Automatic Turret Lathe. Cost, $2800; operating 3250 hours per year; requires 1 operator; hp. required, 3; cost of power, 5 cents per kw-hr. This equipment is not in use on this class of work but was not discarded as plant equipment.

Average Values. Comparison based on lot of 6500 class A hoist gear gages.

Data Required for Analysis

No. 1 Full-Automatic One		1 year = 2400 hours		No. 2 Semi-Automatic One	
		Number of units employed			
$*X_1$ = 100%		Per cent of year employed	(X)	$*X_2$ = 135.4%	
A_1 = 6%		Per cent on investment	(A)	A_2 = 6 %	
B_1 = 1%		Per cent for insurance, etc.	(B)	B_2 = 1 %	
C_1 = 5%		Per cent for upkeep	(C)	C_2 = 6.8%	
D_1 = 10%		Per cent for depreciation	(D)	D_2 = 11.8%	
Total = 22%				Total = 25.6%	
E_1X_1 =	$ 360.00	Cost of power, etc.	(E)	E_2X_2 =	$ 366.00
2400 hr. at 40 cents =	$ 960.00	Cost of labor	(S)	3250 hr. at 75 cents =	$2437.50
59% of payroll =	$ 566.40	Cost of labor burden	(T_a)	59% of payroll =	$1438.13
$I_1(A_1+B_1+C_1+D_1)$ =	$ 737.00	Cost of fixed charges	(T_b)	$I_2(A_2+B_2+C_2+D_2)$ =	$ 716.80
Total for 100% of yr.	$2623.40	Cost of operation		Total for 100% of yr.	$4958.43
	$ 0.00	Value of increased production	(U)		$ 0.00
	$3350.00	Cost of equipment	(I)		$2800.00
Unamortized value of equipment less resale value			(K)		$ 0.00

Valuation of Factors

	$A_1 + B_1 + C_1 + D_1$	=	22 % = $A + B + C + D$
	$E_1 - E_2$	$ 360.00 — $ 366.00 =	— $ 6.00 = E
	$S_2 - S_1$	$2437.50 — $ 960.00 =	$1477.50 = S
	$T_{a2} - T_{a1}$	$1438.13 — $ 566.40 =	$ 871.73 = T_a
	T_{b2}	=	$ 716.80 = T_b
	$U_1 - U_2$	$ 0.00 — 0.00 =	$ 0.00 = U
[2]	$Y_1 = I_1(A_1 + B_1 + C_1 + D_1)$	=	$ 737.00 = Y
	I_1	=	$3350.00 = I
	K_2	=	0.00 = K

* X is applied individually in Cases Nos. 1 and 2, hence 100 % = X

Solutions

Z = Maximum Investment Which Will Return Simple Interest on Investment

[1] $$Z = \left[\frac{(S + T_a + U - E)X + T_b}{A + B + C + D}\right] - K = \mathbf{\$13{,}963.63}$$

V = Yearly Profit from Operation

[3] $$V = [(S + T_a + U - E)X + T_b] - [(Y + (KA)] = \mathbf{\$2335.03}$$

P = Yearly Profit in Per Cent on Investment

[4] $$P = \frac{V}{I} + A = \mathbf{75.7\ per\ cent}$$

H = Years for Complete Amortization of Investment out of Profits

[5] $$H = \frac{100\%}{P + D} = \mathbf{1.16\ years}$$

COMPARATIVE ECONOMIC ANALYSIS NO. 9

Showing values for Z, V, P, and H as per formulas recommended by A.S.M.E. Committee.

It is assumed that the use of equipment No. 2 is generally accepted practice, while No. 1 is under examination for comparative economic efficiency. The factor K should be given zero value unless No. 2 is in use and would therefore be displaced by No. 1 with a corresponding capital loss.

No. 1 (designated by subscript numeral 1): Full-Automatic Turret Lathe. Cost, $3350; operating 2400 hours per year; requires 1/2 operator's time; hp. required, 4; cost of power, 5 cents per kw-hr.

Operated for Equal Production in Comparison with

No. 2 (designated by subscript numeral 2): Semi-Automatic Turret Lathe. Cost $2800; operating 3250 hours per year; requires 1 operator; hp. required, 3; cost of power 5 cents per kw-hr. This equipment is not in use on this class of work, but was not discarded as plant equipment.

Average Values. Comparison based on lot of 6500 class A hoist gear gages.

Data Required for Analysis

No. 1 Full-Automatic One		1 year = 2400 hours		No. 2 Semi-Automatic Two	
		Number of units employed			
$*X_1$ = 100%		Per cent of year employed	(X)	$*X_2$ = 67.7%	
A_1 = 6%		Per cent on investment	(A)	A_2 = 4.06%	
B_1 = 1%		Per cent for insurance, etc.	(B)	B_2 = 0.68%	
C_1 = 5%		Per cent for upkeep	(C)	C_2 = 3.39%	
D_1 = 10%		Per cent for depreciation	(D)	D_2 = 6.77%	
Total = 22%				Total = 14.90%	
E_1X_1 =	$ 360.00	Cost of power, etc.	(E)	E_2X_2 =	$ 366.00
2400 hr. at 40 cents =	$ 960.00	Cost of labor	(S)	3250 hr. at 75 cents	$2437.50
59% of payroll =	$ 566.40	Cost of labor burden	(T_a)	59% of payroll	$1438.13
$I_1(A_1+B_1+C_1+D_1)$ =	$ 737.00	Cost of fixed charges	(T_b)	$I_2(A_2+B_2+C_2+D_2)$ =	$ 834.40
Total for 100% of yr.	$2623.40	Cost of operation		Total for 67.7% of yr.	$5076.03
	$ 0.00	Value of increased production	(U)		$ 0.00
	$3350.00	Cost of equipment	(I)		$5600.00
Unamortized value of equipment less resale value			(K)		$ 0.00

Valuation of Factors

	$A_1 + B_1 + C_1 + D_1$	=	22 % = $A + B + C + D$
	$E_1 - E_2$	$ 360.00 — $ 366.00 =	— $ 6.00 = E
	$S_2 - S_1$	$2437.50 — $ 960.00 =	$1477.50 = S
	$T_{a2} - T_{a1}$	$1438.13 — $ 566.40 =	$ 871.73 = T_a
	T_{b2}	=	$ 834.40 = T_b
	$U_1 - U_2$	$ 0.00 — $ 0.00 =	$ 0.00 = U
[2]	$Y_1 = I_1(A_1 + B_1 + C_1 + D_1)$	=	$ 737.00 = Y
	I_1	=	$3350.00 = I
	K_2	=	$ 0.00 = K

* X is applied individually in Cases Nos. 1 and 2, hence 100 % = X

Solutions

Z = Maximum Investment Which Will Return Simple Interest on Investment

[1] $$Z = \left[\frac{(S + T_a + U - E)X + T_b}{A + B + C + D}\right] - K = \mathbf{\$14{,}498.30}$$

V = Yearly Profit from Operation

[3] $$V = [(S + T_a + U - E)X + T_b] - [Y + (KA)] = \mathbf{\$2452.63}$$

P = Yearly Profit in Per Cent, on Investment

[4] $$P = \frac{V}{I} + A = \mathbf{79.2\ per\ cent}$$

H = Years for Complete Amortization of Investment out of Profits

[5] $$H = \frac{100\%}{P + D} = \mathbf{1.12\ years}$$

different part. The semi-automatic with one cutting tool per operation finished the production in 92 per cent of the time necessary for the full-automatic, but required an individual operator. The outstanding difference in operation was practically only in the amount of labor time involved. Analysis No. 7 gives the results obtained in this case.

Machining Hoist Gear Cages. Another possible analysis of the same-size full-automatic turret lathe and a semi-automatic turret lathe was in operation on a hoist gear cage, an ideal piece for efficient production on the former machine, in which case the time required on the full-automatic was considerably less than on the semi-automatic. The piece required turning at three different diameters three facing operations, an inside turn, and one boring and reaming operation. The semi-automatic lathe with its individual operator required 135 per cent of the time necessary on the full-automatic lathe, with one-half of the operator's time for attention. As it would have been possible to obtain the production on the semi-automatic lathe by running it overtime or by using two machines running approximately 67 per cent of the working year, analyses Nos. 8 and 9 are given to show whatever effect may result from variation in fixed charges.

Machining Hoist Gear Heads. An analysis of the same-size full automatic turret lathe and a semi-automatic vertical turret lathe was possible in a lot of hoist gear heads. The piece required two different turning operations, four facing operations, two different-diameter bores, and a bevel seat turned in one side of the piece. One full-automatic turret lathe worked continuously with one-half of the operator's time for production, while three semi-automatic vertical turret lathes with individual operators were required to run 83.3 per cent of the working year for equivalent production. Analysis No. 10 deals with the above operation.

All of the foregoing analyses demon-

COMPARATIVE ECONOMIC ANALYSIS NO. 10

Showing values for Z, V, P, and H as per formulas recommended by A.S.M.E. Committee.

It is assumed that the use of equipment No. 2 is generally accepted practice, while No. 1 is under examination for comparative economic efficiency. The factor K should be given zero value unless No. 2 is in use and would therefore be displaced by No. 1 with a corresponding capital loss.

No. 1 (designated by subscript numeral 1): Full-Automatic Turret Lathe. Cost, \$3700; operating 2400 hours per year; requires 1/2 operator's time; hp. required, 5; cost of power, 5 cents per kw-hr.

Operated for Equal Production in Comparison with

No. 2 (designated by subscript numeral 2): Semi-Automatic Vertical Turret Lathe. Cost, \$4200; operating 6000 hours per year; requires 1 operator; hp. required, 3; cost of power, 5 cents per kw-hr. This equipment is not in use on this class of work, but was not discarded as plant equipment.

Average Values. Comparison based on lot of 4500 class A hoist gear heads.

DATA REQUIRED FOR ANALYSIS

No. 1 Full-Automatic		1 year = 2400 hours		No. 2 Semi-Automatic	
One		Number of units employed		Three	
$*X_1$ = 100%		Per cent of year employed	(X)	$*X_2$ = 83.33%	
A_1 = 6%		Per cent on investment	(A)	A_2 = 5.00%	
B_1 = 1%		Per cent for insurance, etc.	(B)	B_2 = 0.83%	
C_1 = 5%		Per cent for upkeep	(C)	C_2 = 4.16%	
D_1 = 10%		Per cent for depreciation	(D)	D_2 = 8.33%	
Total = 22%				Total = 18.32%	
E_1X_1 =	\$ 450.00	Cost of power, etc.	(E)	E_2X_2 =	\$ 675.00
2400 hr. at 40 cents =	\$ 960.00	Cost of labor	(S)	6000 hr. at 75 cents =	\$4500.00
59% of payroll =	\$ 566.40	Cost of labor burden	(T_a)	59% of payroll =	\$2655.00
$I_1(A_1+B_1+C_1+D_1)$ =	\$ 814.00	Cost of fixed charges	(T_b)	$I_2(A_2+B_2+C_2+D_2)$ =	\$2308.30
Total for 100% of yr.	\$2790.00	Cost of operation		Total for 83.3% of yr.	\$10,138.30
	\$ 0.00	Value of increased production	(U)		\$ 0.00
	\$3700.00	Cost of equipment	(I)		\$12,600.00
		Unamortized value of equipment less resale value	(K)		\$ 0.00

VALUATION OF FACTORS

	$A_1 + B_1 + C_1 + D_1$	=	22 % = $A + B + C + D$
	$E_1 - E_2$	\$ 450.00 — \$ 675.00 =	— \$ 225.00 = E
	$S_2 - S_1$	\$4500.00 — \$ 960.00 =	\$3540.00 = S
	$T_{a2} - T_{a1}$	\$2655.00 — \$ 566.40 =	\$2088.60 = T_a
	T_{b2}	=	\$2308.30 = T_b
	$U_1 - U_2$	\$ 0.00 — \$ 0.00 =	\$ 0.00 = U
[2]	$Y_1 = I_1(A_1 + B_1 + C_1 + D_1)$	=	\$ 814.00 = Y
	I_1	=	\$3700.00 = I
	K_2	=	\$ 0.00 = K

* X is applied individually in Cases Nos. 1 and 2, hence 100 % = X

SOLUTIONS

Z = Maximum Investment Which Will Return Simple Interest on Investment

[1] $$Z = \left[\frac{(S + T_a + U - E)X + T_b}{A + B + C + D}\right] - K = \mathbf{\$37{,}099.54}$$

V = Yearly Profit from Operation

[3] $$V = [(S + T_a + U - E] - [Y + (KA)] = \mathbf{\$7347.90}$$

P = Yearly Profit in Per Cent on Investment

[4] $$P = \frac{V}{I} + A = \mathbf{204.6\ per\ cent}$$

H = Years for Complete Amortization of Investment out of Profits

[5] $$H = \frac{100\%}{P + D} = \mathbf{0.46\ year}$$

SUMMARY OF ANALYSIS NO. 7

Estimated actual investment required for No. 1............	\$3450.00
Estimated excess investment in No. 1 over No. 2, $I_1 - I_2$, or I_1.	−\$ 350.00
Estimated yearly profit from operation No. 1 over No. 2, excess above simple interest..............................	\$ 985.70
Estimated value of reduced labor turnover................	\$ 0.00
Total..	\$ 985.70
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on investment, total........................	34.5%
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on excess investment, $\frac{I_1}{I_1 - I_2}P$, total..........	0.0%
Estimated time required to amortize entire cost of No. 1 out of earnings in excess of No. 2...........................	2.24 years
Estimated time required to amortize excess cost of No. 1 over No. 2 out of earnings in excess of No. 2 $\dfrac{H}{\frac{I_2}{I_1 - I_2}}$..........	0.0 years

Remarks Covering Relative Flexibility, Safety, Durability, also Recommendation:
The saving shown above, as might be anticipated from the preceding statement, was practically entirely due to the decrease in the labor charge as shown by the comparison of items S_1, T_{a1} with S_2 and T_{a2}. Obviously the use of a considerably more expensive and less efficient machine would still have been justifiable had it been necessary.

SUMMARY OF ANALYSIS NO. 8

Estimated actual investment required for No. 1............	\$3350.00
Estimated excess investment in No. 1 over No. 2, $I_1 - I_2$, or I_1.	\$ 550.00
Estimated yearly profit from operation No. 1 over No. 2, excess above simple interest..............................	\$2335.03
Estimated value of reduced labor turnover................	0.00
Total..	\$2335.03
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on investment, total........................	75.7%
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on excess investment, $\frac{I_1}{I_1 - I_2}P$, total..........	454.2%
Estimated time required to amortize entire cost of No. 1 out of earnings in excess of No. 2...........................	1.16 years
Estimated time required to amortize excess cost of No. 1 over No. 2 out of earning in excess of No. 2 $\dfrac{H}{\frac{I_1}{I_1 - I_2}}$..........	0.193 year

Remarks Covering Relative Flexibility, Safety, Durability, also Recommendation:

SUMMARY OF ANALYSIS NO. 9

Estimated actual investment required for No. 1............	\$3350.00
Estimated excess investment in No. 1 over No. 2, $I_1 - I_2$, or I_1.	−\$2250.00

Estimated yearly profit from operation No. 1 over No. 2, excess above simple interest	\$2452.63
Estimated value of reduced labor turnover	\$ 0.00
Total	\$2452.63
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on investment, total	79.2%
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on excess investment, $\frac{I_1}{I_1 - I_2} P$, total	0.0%
Estimated time required to amortize entire cost of No. 1 out of earnings in excess of No. 2	1.12 years
Estimated time required to amortize excess cost of No. 1 over No. 2 out of earnings in excess of No. 2, $\frac{H}{\frac{I_1}{I_1 - I_2}}$	0.0 year

Remarks Covering Relative Flexibility, Safety, Durability, also Recommendation:

Comparing the results of either Analysis No. 8 or No. 9 with those of Analysis No. 7 shows the increase in savings possible by the reduction in labor charge when the full-automatic was working on a part on which it could show an increase of production over the semi-automatic machine.

Summary of Analysis No. 10

Estimated actual investment required for No. 1	\$3700.00
Estimated excess investment in No. 1 over No. 2, $I_1 - I_2$, or I_1.	−\$8900.00
Estimated yearly profit from operation No. 1 over No. 2, excess above simple interest	\$7347.90
Estimated value of reduced labor turnover	\$ 0.00
Total	\$7347.90
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on investment, total	204.6%
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on excess investment, $\frac{I_1}{I_1 - I_2} P$, total	0.0%
Estimated time required to amortize entire cost of No. 1 out of earnings in excess of No. 2	0.46 year
Estimated time required to amortize excess cost of No. 1 over No. 2 out of earnings in excess of No. 2, $\frac{H}{\frac{I_1}{I_1 - I_2}}$	0.00 year

Remarks Covering Relative Flexibility, Safety, Durability, also Recommendation:

The above analysis exemplifies to a more marked degree the results obtained in Analyses Nos. 8 and 9.

strate very forcibly the economic possibilities of the full-automatic turret lathe on quantity production in which the set-up time for the machine becomes a negligible quantity as distributed over the output.

Labor-Saving Equipment in Road Construction

Description and Economic Analysis of a New Paver, Employing the A.S.M.E. Materials Handling Division's Formulas for Computing the Economies of Labor-Saving Equipment

By E. H. LICHTENBERG,[1] MILWAUKEE, WIS., and JAMES A. SHEPARD,[2] MONTOUR FALLS, N. Y.

This paper describes the economic results obtained by the use of improved equipment for mechanically handling concrete in road construction, which deposits the concrete so nearly into its final position as to require very little manual labor aside from that involved in finishing the surface.

The paper is accompanied by an economic analysis comparing the performance of the improved type of handling equipment with an earlier and less efficient type, in which the Formulas for Computing the Economies of Labor-Saving Equipment are applied.

It is estimated that during the year 1923 there were in the United States between 1000 and 2000 road jobs that employed pavers to mix concrete, directly deposit it upon the subgrade, and move ahead as the concrete was deposited. To handle the concrete from the mixing drum to the subgrade, a boom and bucket has come to be standard equipment.

For years a bucket similar to the one shown in Fig. 1 has been in general use. This type of bucket has two doors at its bottom, placed parallel to the boom. When the bucket reaches a point over the subgrade where the concrete is wanted, a workman on the grade trips the lever on the trolley carrying the bucket and opens the doors. This allows the concrete to drop out of the bottom of the bucket in a heap on the subgrade. The heap is then spaded or spread by laborers until an even layer of 6 to 7 in. is formed. As will be

[1] Ch. Engr., Koehring Co. Mem. A.S.M.E.

[2] Vice-Pres Engrg., Economic Research, Shepard Elec. Crane & Hoist Co. Mem. A.S.M.E. Mr. Shepard prepared the comparative economic analysis (No. 11) accompanying Mr. Lichtenberg's paper.

Contributed by the Materials Handling Division for presentation at the Spring Meeting, Milwaukee, Wis., May 18 to 21, 1925, of The American Society of Mechanical Engineers. All papers are subject to revision.

COMPARATIVE ECONOMIC ANALYSIS NO. 11

Showing values for Z, V, P, and H as per formulas recommended by A.S.M.E. Committee.

It is assumed that the use of equipment No. 2 is generally accepted practice, while No. 1 is under examination for comparative economic efficiency. The factor K should be given zero value unless No. 2 is in use and would therefore be displaced by No. 1 with a corresponding capital loss.

No. 1 (designated by subscript numeral 1): One Koehring Improved Paver. Cost \$7000; operating 1000 hours per year; requires 5 operators; hp. required, 40; cost of power, \$21 per hp. per standard year.

Operated for Equal Production in Comparison with

No. 2 (designated by subscript numeral 2): One Koehring Old-Style Paver. Cost \$7000; operating 1000 hours per year; requires 9 operators; hp. required, 40; cost of power \$21 per hp. per standard year. This equipment in use 3 years. Unamortized value, \$2800.

Average Values. None.

Data Required for Analysis

No. 1 Koehring Improved Paver		1 year = 2400 hours		No. 2 Koehring Old-Style Paver	
One		Number of units employed		One	
$^*X_1$ = 41%		Per cent of year employed	(X)	$^*X_2$ = 41%	
A_1 = 5%		Per cent on investment	(A)	A_2 = 5%	
B_1 = 2%		Per cent for insurance, etc.	(B)	B_2 = 2%	
C_1 = 18%		Per cent for upkeep	(C)	C_2 = 18%	
D_1 = 20%		Per cent for depreciation	(D)	D_2 = 20%	
Total = 45%				Total = 45%	
E_1X_1 =	\$ 344.00	Cost of power, etc.	(E)	E_2X_2 =	\$ 344.00
5000 hr. at 45 cents	\$2250.00	Cost of labor	(S)	9000 hr. at 45 cents	\$4050.00
20% of payroll	\$ 450.00	Cost of labor burden	(T_a)	20% of payroll	\$ 810.00
$I_1(A_1+B_1+C_1+D_1)$ =	\$3150.00	Cost of fixed charges	(T_b)	$I_2(A_2+B_2+C_2+D_2)$ =	\$3150.00
Total for 41% of yr.	\$6194.00	Cost of operation		Total for 41% of yr.	\$8354.00
		Value of increased production	(U)		
	\$7000.00	Cost of equipment	(I)		\$7000.00
		Unamortized value of equipment less resale value	(K)		\$2800.00

Valuation of Factors

	$A_1 + B_1 + C_1 + D_1$		= 45 % = $A + B + C + D$
	$E_1 - E_2$	\$ 344.00 — \$ 344.00	= \$ 0.00 = E
	$S_2 - S_1$	\$4050.00 — \$2250.00	= \$1800.00 = S
	$T_{a2} - T_{a1}$	\$ 810.00 — \$ 450.00	= \$ 360.00 = T_a
	T_{b2}		= \$3150.00 = T_b
	$U_1 - U_2$	\$ 0.00 — \$ 0.00	= \$ 0.00 = U
[2]	$Y_1 = I_1(A_1 + B_1 + C_1 + D_1)$		= \$3150.00 = Y
	I_1		= \$7000.00 = I
	K_2		= \$2800.00 = K

* X is applied individually in Cases Nos. 1 and 2, hence 100 % = X

Be sure to bring this copy with you to the Spring Meeting

Solutions

Z = Maximum Investment Which Will Return Simple Interest on Investment

$$Z = \left[\frac{(S + T_a + U - E)X + T_b}{A + B + C + D}\right] - K = \mathbf{\$9000} \quad [1]$$

V = Yearly Profit from Operation

$$V = [(S + T_a + U - E)X + T_b] - [Y + (KA)] = \mathbf{\$2020} \quad [3]$$

P = Yearly Profit in Per Cent on Investment

$$P = \frac{V}{I} + A = \mathbf{33.8\ per\ cent} \quad [4]$$

H = Years for Complete Amortization of Investment out of Profits

$$H = \frac{100\%}{P + D} = \mathbf{1.8\ years} \quad [5]$$

SUMMARY OF ANALYSIS NO. 11

Estimated actual investment required for No. 1	\$7000.00
Estimated excess investment in No. 1 over No. 2, $I_1 - I_2$, or I_1	\$7000.00
Estimated yearly profit from operation No. 1 over No. 2, excess above simple interest	\$2020.00
Estimated value of reduced labor turnover	\$ 0.00
Total	\$2020.00
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on investment, total	33.8%
Estimated yearly profit from operation of No. 1 over No. 2 in per cent on excess investment, $\frac{I_1}{I_1 - I_2}P$, total	33.8%
Estimated time required to amortize entire cost of No. 1 out of earnings in excess of No. 2	1.8 years
Estimated time required to amortize excess cost of No. 1 over No. 2 out of earning in excess of No. 2, $\frac{H}{\frac{I_1}{I_1 - I_2}}$	1.8 years

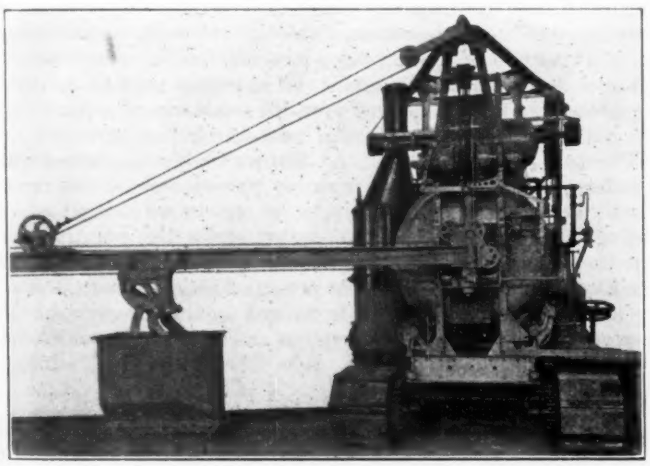

Fig. 1 Paver Provided with Dumping Bucket

noted in Fig. 2, as many as six men may be required, the minimum number being three, varying according to the consistency of the concrete or other conditions.

An improved bucket, however, has been recently developed as shown by Fig. 3. This bucket has only one door at its bottom, placed crosswise to the boom, the dimensions of the opening being approximately $4^1/_2$ ft. by 10 in. When the operator of the machine has the bucket filled it is run out to the point of deposit; reversing the direction of travel automatically opens the bucket door to an extent which is regulated by adjustable stops, thus, as the bucket moves along the boom, feeding a stream of concrete over the subgrade in an even layer of the desired thickness and between four and five feet wide.

This process is repeated until the entire subgrade is covered, when the machine moves forward the length of the boom. Little or no spading is required with this type of bucket, and but two men in place of six are so employed, as shown by Fig. 3. Under favorable conditions a single laborer may perform all of the manual work required.

A simple mechanical-handling device, by placing the concrete practically into its final position, renders it possible to release within the United States several thousand laborers for other employment without increasing the investment required or other items of cost of operation, and at the same time to increase the net efficiency of operation.

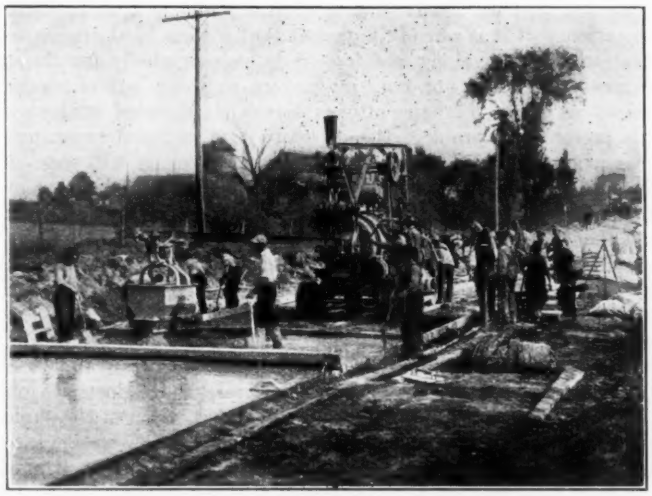

Fig. 2 Paver of Fig. 1 in Operation

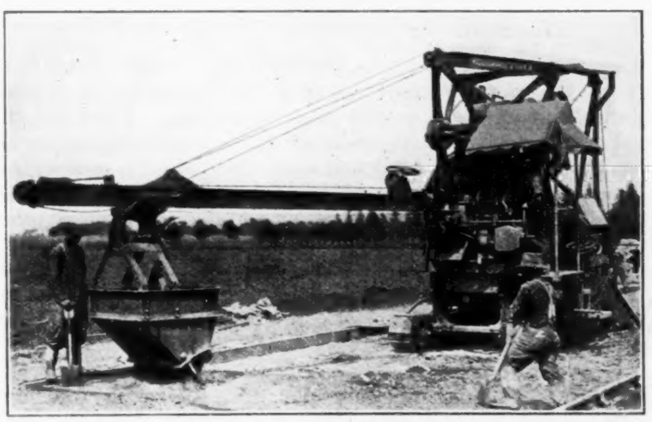

Fig. 3 Paver Provided with an Improved Bucket that Travels Along Boom and Feeds Concrete Over the Subgrade in an Even Layer

A National Apprenticeship Program

By HAROLD S. FALK,[1] MILWAUKEE, WIS.

THE shifting of the emphasis, however slightly, from production to personnel within recent years in American industry is nothing if not significant. A few years ago we were to arrive at our industrial salvation by a wholesale introduction of automatic machines and the installation of foolproof systems. This craze, however, soon had its fling. It became more and more apparent that so long as human beings are necessarily concerned in one way or another in our manufacturing and commercial enterprises, they must be given some consideration. That consideration has lately, in increased measure, taken the form of education. And this in its higher aspects is apprenticeship. Thus while American industry is more and more concerned with the problem of providing for itself a trained and skilled personnel, it has come face to face with the problem of apprenticeship.

We are just at the beginning of this movement of industrial education, but it is already apparent that a mere local application of apprenticeship along isolated trade lines is wholly insufficient to meet the needs not only of modern industry but of modern society as well. Perhaps after a somewhat detailed analysis of this present-day problem the necessity of a national program of apprenticeship in all trades and some professions will seem an obviously logical conclusion. At any rate there will be no harm in an analysis of this kind, if only because the nature of the remedy will then become clearer. However, it is our hope and intention to show the necessity of a national program of industrial education in every major trade and industrial profession in modern society. It is significant that even some of the old professions like medicine have returned to the apprenticeship method, through internships, etc.

This American workshop of ours is made up of an almost infinite number of professional, commercial, and industrial jobs. Until a few years ago we filled a considerable portion of the skilled jobs with Europeans, trained for the work. But now we are faced with the necessity of filling these same ranks with American-trained youths. This has made it necessary that we again consider the efficacy of the old method, and perhaps the only method, of training on the job, that is, apprenticeship.

Apprenticeship a Quarter of a Century Ago

Can this method be made effective under modern conditions? Let us glance for a moment, before giving our answer, at apprenticeship as it existed a quarter of a century ago. There was the small establishment which contained in its manufacturing operations all the essentials of any and every trade which it represented. The employer, who had not as yet been separated even by a private office from his employees, was, in addition to his many other duties, a father as well as an instructor to the apprentices in whom he took such a just pride. Seldom were mechanics imported via the employment office; in fact, they were almost always, if not entirely so, "made" in the plant. In other words, these establishments were producers of mechanics rather than mere users.

Let us note briefly the essentials of this rather successful training scheme: First, a "tradition" for the training of mechanics, even though this was in some measure a remnant of the European tradition, brought over by the trained mechanics, who then invaded our shores. Second, all the essentials of a complete trade or trades wrapped up in the manufacturing operations however small their scale. Third, the essentials of an adequate instructional program. The "Old Man," who for obvious reasons was interested in the perpetuation of his enterprise, made the instruction of his boys a major part of his own task. Thus instruction was bound to be effective, direct, personal, and comprehensive, though finesse was undoubtedly lacking. Hence there was present a tradition for training, the essential material for an adequate program, and the necessary effective instructional equipment.

Apprenticeship as Affected by the Changes that have Taken Place in Modern Industry

And now with this in mind let us glance hastily at the transformation that has taken place in modern industry. Two elements have entered into present-day industrial life that have changed almost completely this whole problem of industrial education. Specialization of operations and division of labor have atomized our industrial life and broken down our major trades and professions to such an extent that but few of our manufacturing establishments are able to present complete and adequate programs for the training of the skilled personnel necessary to vitalize our industrial life.

As a result but few of the larger industrial establishments in any community are capable of presenting adequate training programs. These in turn have found it impossible, if indeed they attempted at all, to train a skilled personnel sufficient for their entire community. The smaller establishments, whose operations under present conditions comprise but a portion of the trades they represent, have long since discovered an insurmountable obstacle to training apprentices. They were unable to interest young men in a formal apprenticeship because it was impossible for them to present an adequate training program.

Thus with the burden shifted to the few larger plants in any community, apprenticeship has dwindled more and more. And the tradition of training has gradually faded until at present the term apprenticeship has little meaning, unless it be an odious one. These two factors, namely, lack of a tradition and lack of material for adequate programs of industrial education, have operated powerfully to destroy even the semblance of a possibility of making apprenticeship effective in modern industry.

There are of course exceptions. But we are here concerned with a general condition which is probably proven best by the exceptions. American apprenticeship, if it can be so designated, is distinguished by a few outstanding examples the country over. But there is not an industrial community in America today that is self-supporting or solvent in its personnel phase. And the vitality of our industrial life must be judged by the solvency, in this respect, of our individual communities and not by a few individual plants.

What Does Industry Offer the Young Man Today?

It may not be amiss to consider this rather sad state of affairs from another side. We have glanced, as it were, at the situation as it exists in our manufacturing establishments. Let us glance for a moment beyond these walls into the life that surrounds them.

Here is a young man who has completed his formal education and is prepared to enter upon his life work. What does he face? An industrial life to him is completely disorganized as regards the vocation it has to offer and the jobs by means of which he might attain, consciously or otherwise, to some definite objective. Our industries are characterized more by figures of production than by trades and occupations. He knows of one concern that it produces so many *things* a month, of another that it turns out so many *tons* of material. But he has yet to learn what trades and professions are involved in the making of these things and the producing of these tons. And perhaps for the most part industry itself is unconscious of the essential vocational content of its operations. Our young man has come into an unorganized life in which he must both determine for himself his own vocation as well as the proper routine whereby he can arrive at his vocational objective.

The very complexity of modern industry makes it seem a hopeless task to determine the essential vocational lanes by means of which a young man can find his way through to some definite goal. And indeed there should be little wonder in this, since it is a matter of conjecture and experiment even among vocational experts. The essential trades and professions have been broken down into such small fragments that it has become a real puzzle to piece them together into a composite and harmonious whole.

[1] Vice.-Pres. and Works Mgr., The Falk Corporation. Mem. A.S.M.E.

Contributed by the Committee on Education and Training for the Industries, for presentation at the Spring Meeting, Milwaukee, Wis., May 18 to 21, 1925, of The American Society of Mechanical Engineers. All papers are subject to revision.

Alongside of this problem, and, undoubtedly as a result of it, has grown a rather universal disregard for true vocational training and education. All strata of society are more or less involved in the abandonment of this idea. Our formal educational system has come to ignore it quite completely. Scarcely anywhere is vocational training, industrial education, or apprenticeship a vital concern in the lives of the American people.

In thus stating the problem we are in no wise concerned with the placing of the blame. It has probably and undoubtedly come as part and parcel of the evolution of modern industry. Moreover to fix the blame would be of little benefit. It should be our main concern to remedy it as well and as quickly as possible.

Requisites for an Adequate Program of Industrial Education

To make effective, therefore, an adequate program of industrial education that will meet our present needs we must have, first, the materials at hand that will justify a complete and full scheme of training, second, effective instructional equipment, and third, an adequate tradition that will bear along and give moral support to this program.

Upon this foundation we shall build our program for an adequate apprenticeship. In order that each industrial community can become self-supporting in its personnel aspect, all establishments in those communities must unite to supply the training that is necessary. But the majority of the smaller establishments are unable, alone and separately, to present a real training program. There must be a grouping of these plants along trade lines in such manner that the groups can present adequate and effective programs of industrial education. This must become a community affair in which all of the interested elements do their proportionate share in this scheme of training. There must be a community organization to organize, establish, and coördinate groups that can present adequate programs of training.

Proper vocational education of the related type that must necessarily accompany true apprenticeship must also be established on a community basis. All elements that are and should be interested must give the proper support to a centrally located institution which can provide for them the only possible means of adding the related classroom instruction so essential in a formal apprenticeship. Small industrial establishments under the very best possible circumstances would be unable, even if they desired, to add this essential element of the training. The larger establishments could ill afford to attempt it individually if only because of the ill effect that such an arrangement would have upon a community program. The vocational educational institution must be the rallying ground for this community enterprise. In this way only can all of the industrial and commercial interests be adequately served in proportion to their just needs.

Milwaukee's Experiment in Vocational Education

Milwaukee is at present engaged in carrying on an experiment of this kind. The metal-trades industries have united on a community basis to promote an adequate program of industrial education. Coöperatively they are making this community self-sufficient and independent in its supply of skilled mechanics.

This group of trades early realized that it would be impossible to make a program of industrial education wholly effective if but few of the larger plants were engaged in these training activities. Hence training groups were formed in which smaller organizations were arranged about the larger in such manner that the groups were able to present a complete and adequate program of training. Thus, apprentices are exchanged between smaller and larger plants according to a prearranged plan.

A district director has been engaged to coördinate the activities of the various groups, to promote apprenticeship whenever necessary, and to gather together all the ends of the multitudinous details that are always a part of a large community project of this kind.

Under the auspices of the community metal-trades organization and at the direction of the district supervisor, an effective promotional program has been made a part of the annual activities. Inspirational gatherings of apprentices, parents, and employers have been held which culminate in an annual dinner entertainment. At the last of these more than a thousand Milwaukee metal-trades apprentices and employers were present.

The Community Program Closely Related to the Public-School System

This community program includes a very close and definite relationship to the public-school system, particularly the local vocational school. This institution has become the hub about which this whole training scheme revolves. Not only do apprentices attend the vocational school part time during their apprenticeship, as required by law, but they also attend full time during a part or all of their probationary period. These full-time classes have given a prestige to apprenticeship among young prospectives to an extent that no other arrangement could possibly have done. Beyond this, however, the vexations incident to the necessary vocational-guidance work among probationary apprentices has been removed from the shop foremen, who are already sufficiently burdened with certain portions of this training work.

Thus the part-time school has become a very essential and necessary instrument in the promulgation of this plan. Without it the smaller plants would be unable to give any related trade training. Without it the larger plants would have the whole community program upon their hands and would have an onerous burden upon their shoulders which could be more efficiently dealt with by the vocational school in conjunction with the above organization. The Milwaukee Vocational School under the direction of Mr. R. L. Cooley cannot be given too much credit for whatever success the Milwaukee plan has achieved. Through its leader it has not only administered efficiently but coöperated magnanimously.

Milwaukee has ceased to talk apprenticeship in terms of the individual plant. It considers the problem only from the community viewpoint.

A National Organization to Promote Apprenticeship Needed

But Milwaukee realizes that it cannot stand alone. If its work is to endure and enjoy a permanent success, each and every American industrial community must carry on a similar community apprenticeship. In other words, a national program is essential.

Unless this work be conceived on a national basis and a national organization be endowed with the powers to promote, administer, and traditionalize apprenticeship, an isolated success like that of Milwaukee will become temporary and gradually vanish. Every American industrial community must be made an intimate part of this scheme of industrial education. In no other way can we as a nation sustain our industrial supremacy. In no other way can we as a nation—and this is more fundamentally important—be perfectly fair and just to each young generation as it passes out into the world of work and accomplishment. We need a national organization and a national plan to inaugurate a promotional program such as will once and for all place apprenticeship in its proper place in our economic order. Some years ago, in 1912 to be exact, a safety congress that convened in Milwaukee burst the bonds of provincialism and started what at the present time has become the greatest national advertising campaign in history. From Milwaukee the inspiration to a national effort for universal safety went forth and became shortly not a community but a national crusade.

"Safety" has become a household slogan. "Apprenticeship" must become a similar slogan. We must make of our efforts through a national body, properly endowed and supported, a nation-wide crusade that will enkindle this light of the new industrial education in every American community. We need a national organization to *promote* apprenticeship.

We need a national organization with a national program to administer apprenticeship. This burden of training must be properly apportioned among our communities. Data, and educational and instructional matter must be gathered and assimilated, to be used again where its effectiveness will be greatest. A national clearing house of this kind is indispensable. The rules of the game must be laid down and administered so that all can act justly and fairly in carrying on their share of the work. Such reserve of strength as a national organization can encourage the faltering, strengthen the weak, convert the unbelieving, and administer the burden justly among those who are active.

The Tradition of Apprenticeship Needed Again in Modern American Industrial Life

But above all and foremost do we need to revitalize the tradition of apprenticeship in modern American industrial life. Not only must our industries prepare a planned life for the young people they receive, but the parents of these young people must come to regard a planned life as of the highest importance. Apprenticeship must be for them but a continuation of the education of their children. It must in fact become as important as an education and as a vital and integral part of it. Unless this be made the objective of a national program, it must fail. Its moral force, its reserve of power, and its prestige can force the attention of all elements in present-day American society to this problem of industrial education. In this way only can the tradition of apprenticeship be reëstablished and revivified.

Milwaukee has achieved some success with this program of apprenticeship. All members in its community have begun to give that place to apprenticeship in their lives which it justly deserves. The metal-trades group has made more than a beginning toward the accomplishment of this program. Strong traditions of prejudice that have almost strangled certain trades have been broken. Mothers and fathers are beginning to consider apprenticeship quite as necessary as a formal education. But unless Milwaukee can be supported in this work by every American industrial community, it can never hope for final success. Until apprenticeship in all lines to which our American youths are admitted is generally and universally established upon a national basis and promoted, organized, and supported by a national organization, Milwaukee can ill afford to, nor does it, glory in its apprenticeship achievements.

Elimination of Unnecessary Fatigue in Industry

Abstract of Report of Committee to the A.S.M.E. Management Division

By PROF. GEORGE H. SHEPARD,[1] PURDUE UNIVERSITY, LAFAYETTE, IND.

The last report to the A.S.M.E. on fatigue elimination was made at the Annual Meeting in 1923 by the late Major Frank B. Gilbreth. Since that time there have been no noteworthy developments. Dr. Lillian M. Gilbreth has a vast amount of data on the subject, but they have not yet been analyzed and classified.

The British Government has organized an Industrial Fatigue Research Board to carry out investigations with a view to finding out the most favorable hours of work and other conditions of employment applicable to industrial occupations. Reports of this Board are often useful in the solution of industrial problems, and can be obtained from H. M. Stationery Office, 28 Abingdon St., London, S. W. I. It is urged that the A.S.M.E. suggest to the American Engineering Council that it point out to the Secretary of Commerce the need for similar governmental activity in America.

Quantitative data regarding the effect of fatigue on production are lacking, although to the engineer this phase of the subject is of great interest. It is well known that improper seating, nervous disorders growing out of unfavorable working conditions that bring about fatigue, and the serious eye strains caused by faulty illumination, all result in a very appreciable drain on productive capacity. Eye fatigue will be studied under standardized conditions in extensive experiments contemplated by Dr. C. G. Brandenburg, Professor of Educational Psychology, C. A. Brown, C. T. Shuh, and the writer at Purdue University during the next year.

Temperature and humidity of the air, and correct ventilation are important elements in reducing industrial fatigue. The katathermometer has been invented by Dr. Leonard Hill to measure the cooling power of the air on the human body, since this action has a decided influence on the problem of ventilation.

The British Industrial Fatigue Research Board have started an investigation into the design of machinery in relation to the requirements of operation. In the past, machines have been designed from the mechanical rather than from the manipulative aspect.

Research on muscular fatigue, and on the necessary frequency and duration of rest periods to overcome fatigue, is being continued at Purdue University.

Prof. Henry J. Spooner, of London, reports that he is making a special study of noise as it affects industrial fatigue. He states that the National Physical Laboratory during 1924 equipped special rooms for the study of sound and developed special apparatus for testing. Particular attention has been devoted to an investigation into the sound-absorptive values of different kinds of materials used in building construction, and equipment for large-scale tests is being provided. The acoustic properties of buildings are receiving attention. Photographic studies of sound waves are also in progress.

Professor Spooner further predicts that before long noise will receive as much attention from hygienic authorities as noxious fumes, lighting, heating, ventilation, and sanitation, as an important factor in industrial activity.

The coöperation and interest of the A.S.M.E. in the effort to cut down the waste in industry that comes from unnecessary fatigue is greatly appreciated by the Committee of the S.I.E.

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[1] Chairman of Committee on Elimination of Unnecessary Fatigue, Society of Industrial Engineers. Mem. A.S.M.E.

Factors Concerning the Economics of Shopping Steam Locomotives

The Folly of Continuing Obsolete Designs in Service—Trend of Unit Costs Since 1910—Effect of Specific Shopping Policy on Cost of Repairs—Bearing of Utilization of Power on Shopping Policy, etc.

By L. K. Sillcox,[1] Chicago, Ill.

THE successful manufacturer must know the units of cost to produce his wares, for upon their application depend his profits. The universal adoption of more or less detailed cost accounts in both large and small establishments and the greater scrutiny given to them by owners and managers are real evidence of the value of such knowledge and the necessity therefor. Knowing that such information is successfully determined and applied in the commercial world, surely it can be as effectively established and employed in the matter of railroad-locomotive maintenance and be the basis of executive policy with a view toward assisting the average motive-power man in carrying out evident possibilities for economy and an effective procedure at least cost.

Economies are of two kinds: internal economies which can be carried out independently by the mechanical officer of his own motion; and the much greater economies which management, as a whole, can only make possible, based on current studies as to policies and possibilities. Perhaps one main reason why the justice of the principles above stated is not more readily conceded is to be found in the fact that it is oftentimes regarded as exceptional. The truth would rather seem to be that railroads are only typical of the more modern business organizations, and should seriously study, regardless of known obstacles, what the possibilities really are, and then constantly endeavor, item by item, to make progress along fundamental lines; all of which, for the purpose of our discussion, revolves around the question of the proper utilization of motive power. In truth, though we have emphasized the point of management policy and imagined an executive fixing a complete system, yet no one man, and indeed no combination of men, could evolve a best method off-hand from the foundation. It can only grow gradually, developing here and changing there, in line with economy, as the territory requires or the nature of the traffic and the competition in attracting it become an issue. But the guiding idea of management having a proper and stable policy remains the same throughout.

The serious question we have before us is the necessity of deciding upon an accurate unit of measure. We need correct and simple facts, susceptible of a clear and concise understanding on the part of all concerned, and clear as well as quick application by railway officers charged with the duties of maintenance and operation. The expenditure for locomotive maintenance so far as it is caused by frictional wear and tear will evidently increase in direct proportion to the strain of the work imposed upon the locomotive; at the same time, to the extent it represents outlay for replacement of parts, obsolete though not worn out, so far it is independent of work done. Any plan used in the shopping of power involves complete consideration as to necessary maintenance and the effect from characteristics of service, as well as details of motive-power construction, age and availability of shop, roundhouse facilities, etc. Maintenance may be defined as the upkeep or replacement of parts as due, based on individual consideration of each item with respect to limits of wear, strength requirements, and reliability factors. The accounting for the cost of maintenance varies with the type of property. Maintenance of locomotives, for instance, when finally accumulated for the year and reported as required by the Interstate Commerce Commission's classification of accounts, embraces not only the labor and material applied together with the allocation of direct overheads, such as shop expense, power-plant distribution, store expense, etc., but the depreciation and retirement charges. The carrier has the option of determining the rate at which depreciation shall be charged and accumulated currently, but the general principle is to apply a rate somewhat consistent with the estimated total life after deducting the estimated amount of salvage recoverable when the unit is dismantled. Any depreciation which is not sufficient when a locomotive is retired is made up by retirement charges applied against the locomotive-maintenance account at the time of dismantling; therefore equipment maintenance is charged currently with paying off the investment as well as overcoming wear and deterioration. The maintenance of fixed structures, such as bridges for instance, is charged currently as actually incurred, no depreciation being accumulated during the life of the bridge but the entire investment being charged off to operating expenses at the time of final retirement. Taking these facts into consideration, therefore, a fixed structure, having a longer life than equipment, requires a lesser rate of renewals, and a bridge costing new \$64,000 as compared with a new locomotive costing the same amount will incur a final average charge for maintenance and retirement of approximately 4 per cent as compared with approximately 15 per cent per year for a locomotive. However, in considering the subject as a whole from an equipment standpoint, we are able to segregate the direct repair cost from other charges, the repairs being confined to a sub-account in the classification, which involves labor plus shop expense, and material plus store expense. It is a fact that in not a few instances much of the expenditure for locomotive maintenance, as reflected in the accounts, is occasioned from patching up old construction, even though in some cases this does extend to the point where the actual repair cost, as renewed, exceeds the major portion of the value of the unit as renewed and, consequently, is recapitalized; in which event, nevertheless, the retirement expense must be carried in maintenance.

The Folly of Continuing Obsolete Designs in Service

A close study will very often indicate the folly of spending large sums per unit to continue obsolete designs in service for long periods when the same amount would be more than sufficient, as an initial cash payment, for an up-to-date efficient design of greater capacity and less cost to operate or maintain. Let us test this by imagining a concrete case. Assume that a passenger engine fifteen years old and originally designed to handle a nine-car train is now required to carry fifteen cars on the same schedule, resulting in a heavy maintenance cost due to frame breakages, racking of machinery, valve motion, running gear, etc. Then it becomes a question of not only maintenance but investment. If the original unit was of 40,000 lb. tractive effort and was costing an average of \$9000 per year to maintain with a relatively low record of 3000 miles per month, then it would seem proper to consider a new type of power, say, with 50,000 lb. tractive effort which would afford 5000 miles of service per month and yet not cost more than \$5000 per year for maintenance, making a saving of approximately \$4000 per year in maintenance cost and increasing the performance 66 per cent. This would justify making a change in power even though the original unit might have cost \$30,000 and the new unit would cost \$60,000. The original unit involved a maintenance cost of \$9000 per year plus a depreciation charge of \$750, or a total of \$9750 as compared with an estimated maintenance cost of \$5000 per year for the new unit plus \$1500 depreciation charges or a total of \$6500, making a saving in the new unit of \$3250 per year, to say nothing of additional savings in fuel and transportation expenses. At 6 per cent this recovery would represent an investment of \$54,000, or almost the cost of the new unit, but if this were done on a large scale then the amount of work would be performed with 66 per cent of the number of new units as compared with the number of old units, and thus the change would be justified. It should be understood, however, that

[1] Mech. Dept., C. M. & St. P. Ry. Co. Mem. A.S.M.E.

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passenger service is more constant than freight, so that this example is not presented with the idea that such a reduction in the number of units is possible in passenger service, but is more applicable to freight service. The extent to which carriers are developed along this line reflects in a general way upon the maintenance policy and the cost. Obsolescence of locomotives is a very indefinite measure and its application, in general, is entirely according to local conditions. A locomotive will grow obsolete and costly to operate even if it only remains standing, and this same factor will become of increased importance if it is kept constantly in operation for a long term of years without substantial improvement to care for advanced practice, due to transportation losses from excess fuel consumed or questionable reliability in service affecting train movements. For this reason it would seem a wise plan to obtain all the mileage possible from locomotives, so that the time when they are worn out may arrive at least as soon as the stage when they become out of date.

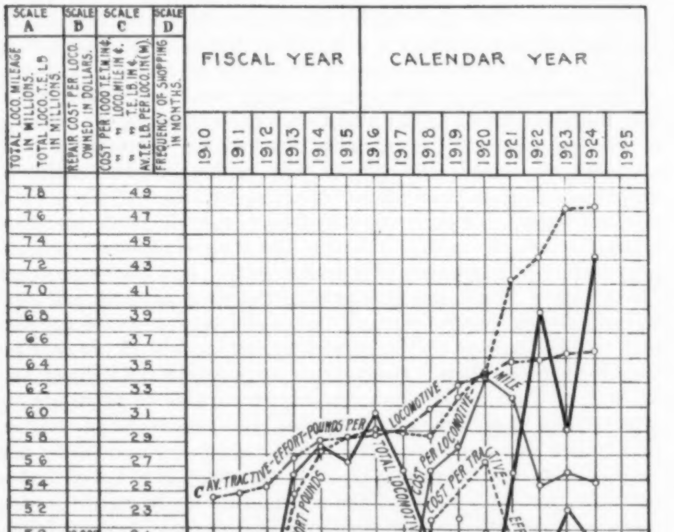

FIG. 1 DATA OF STEAM-LOCOMOTIVE REPAIRS AND PERFORMANCE, C. M. & ST. P. RY., 1910–1924

POLICY USED IN SHOPPING POWER A CENTRAL FACTOR

The same idea of promoting efficiency may be applied to the method employed in shopping locomotives, all of which resolves itself largely into a consideration of the program or the plan employed as best suited by any given administration. There are many elements in the matter of executive policy which go to make a relatively high or low maintenance cost, and the method of shopping power is one of the primary features to be considered. It is possible to hold different opinions as to the attitude which it is proper to assume, but aside from the variation in the characteristics of power owned, when comparing the performance of a number of administrations it may be said that the policy used in the matter of shopping power becomes a central factor and may be considered as the hub of the force at play. The range of possibilities in any given case may be easily determined from a study of practices obtaining on various systems, but, as a matter of fact, there are two extremes, with many variations between them. One is what may be termed the "high-frequency-shopping" and the other the "low-frequency-shopping" policy. The high-frequency-shopping policy is that based on running locomotives through shops with an anticipated service of from twelve to fourteen months with a minimum of roundhouse attention. The low-frequency-shopping policy is that based on running locomotives through shops with the idea of having a service of 24 months or more and with a greater degree of roundhouse attention to attain this length of service. Vital elements in determining such a policy are the relation of the number and size of locomotives owned to the business handled, the road conditions for hauling heavy- or light-tonnage trains, the topography of the country traversed, the distribution of industrial centers, the presence of large terminals, the spacing and capacity of roundhouses, the distribution and assignment of power, the placement of forces as between roundhouses and back shops, the rapidity with which mileage is run out, and particularly the roundhouse and back-shop facilities for handling certain classes of work. Furthermore, where a railroad has back shops of an obsolete character it is practically as well off doing its work in roundhouses, and it may be found helpful under such conditions to construct small modern back-shop facilities at critical points to care for division requirements without increase in overhead expense.

TREND OF UNIT COSTS SINCE 1910

The results obtaining under the two extremes of policy mentioned have been observed for a considerable period, and it appears that policy is largely governed by local conditions rather than local conditions being governed by policy. The road with which the author is connected has had experience under both plans, and just as a case in point, the general results obtained will be stated. Prior to 1921 a high frequency of back-shop repairs was employed, but after considerable study the plan was changed to a low frequency of repairs. The trend of unit costs, etc., both prior and subsequent to 1921, is illustrated in Fig. 1. This chart is a graphic illustration of the results obtained under these two extremes of policy, affected, of course, by the price trend of labor and material in the meantime. The lines plotted represent three general groups, one indicating the growth and size of units maintained, another the various unit costs of maintenance, and a third the frequency of back-shop repairs. The growth of property maintained is represented by the dotted line *A*, which indicates the total tractive-effort pounds owned from 1910 by years to the end of 1924. This growth was not all in the nature of new equipment but represents power added by the acquisition of subsidiary and leased lines as well as some new equipment, and to that extent the growth line should not be confused with the rate at which new equipment might have eliminated obsolescence. This very fact has a marked bearing on the cost of maintenance, as the total growth consisted of approximately as many of the smaller and older locomotives as of the acquisition of the larger and newer types. As to whether or not this extension of property was consistent with the growth of business naturally depends upon how the acquired lines may have increased the amount of business in relation to the amount of property. It is not desired to elaborate here upon the principles of the proper rate of growth of property, but merely to state that the method of computing the proper growth would be to determine the gross revenues per locomotive owned, affected somewhat by the characteristics of the lines added as to their ability to function on a high or low unit train-tonnage basis. Nevertheless the growth of property represents a serious problem in the matter of having back-shop development keep pace with it and of getting continuous use from power. Fig. 1 also shows the increase in the average size of locomotive expressed by the mean tractive-effort pounds per locomotive owned. The size of locomotives is an element in the unit cost of maintenance, and it will be noted that this figure increased from approximately 24,000 tractive-effort pounds per unit to 36,000 in 1924, or approximately 50 per cent. The chart is confined to steam locomotives only, electric locomotives being a separate and distinct problem. It is not possible to state whether the growth in locomotive ownership increased more or less than the revenues or the average train load, as these data are not available from the subsidiary and leased lines.

The feature in Fig. 1 which is deserving of closest study is the line *D* representing the frequency of back-shop repairs. This is arrived at by dividing the total yearly classified-repair output into the total owned throughout the year, which expresses the number

of years between shoppings thus developed, and this of course varies from year to year according to the difference in the number of locomotives owned or used and the output. This is based upon a classification of repairs instituted during federal control and is translated back to 1912. This classification runs as follows:

CLASS 1: New boiler or new back end. Flues new or reset. Tires turned or new. General repairs to machinery and tender.
CLASS 2: New firebox, or one or more shell courses, or roof sheet. Flues new or reset. Tires turned or new. General repairs to machinery and tender.
CLASS 3: Flues all new or reset. (Superheater flues may be excepted.) Necessary repairs to firebox and boiler. Tires turned or new. General repairs to machinery and tender.
CLASS 4: Flues part or full set. Light repairs to boiler or firebox. Tires turned or new. Necessary repairs to machinery and tender.
CLASS 5: Tires turned or new. Necessary repairs to boiler, machinery, and tender, including one or more pairs of driving-wheel bearings refitted.

General repairs to machinery will include driving wheels removed, tires turned or changed, journals turned, if necessary, and all driving boxes and rods overhauled and bearings refitted, and other repairs necessary for a full term of service.

Running repairs unclassified.

Suffix "A" to any class of repairs will indicate that the repairs are required on account of accident.

"B" will show the initial application of stoker.

"C" will indicate the initial application of superheater.

"D" will indicate the initial application of outside valve gear.

"E" will indicate locomotive was converted from compound to simple or from one type to another.

Mallet locomotives will be indicated by a star following application.

Locomotives receiving Class 1, 2, or 3 repairs must be put in condition to perform a full term of service in the district and class of service in which they are to be used.

Class 4 repairs not less than 1/2 term.

Class 5 repairs not less than 1/4 term.

It may be generally conceded that the above is not sufficiently specific to be a complete measure of output since the divisions are not based on work units to a great enough degree to permit of judging shop output in detail.

COST OF REPAIRS PER 1000 TRACTIVE-EFFORT TON-MILES

The variation in the trend of line D is entirely dependent upon the allotment of labor and materials available for maintaining equipment. The shopping frequency increased gradually from 1912 to 1920, and during the latter year locomotives were going through at the rate of once every 14.28 months. In 1921 a committee was appointed to report upon the economics of shopping power, as a result of which it will be noted there was a radical change in the frequency of back-shop classes of repairs subsequent thereto. This study related particularly to the situation existing on the Chicago, Milwaukee & St. Paul Railway and is not offered as a criterion for the reason that other conditions often determine whether or not such a policy is applicable to any but a specific case. The frequency of shopping trend, expressed both in years and in months between shoppings, was as follows:

Year	Years between shoppings	Months between shoppings
1920	1.19	14.28
1921	2.20	26.40
1922	3.30	39.60
1923	2.50	30.00
1924	3.70	44.40

The change in plan necessarily brought about some modification in the distribution of machine tools and facilities in back shops and roundhouses. Great care had to be employed to avoid deferred maintenance under such a transition because of the high cost incident to overcoming deferred maintenance promptly and adequately were this condition to have obtained. The roundhouses were partially equipped to do the necessary machinery and running repair work and in some cases rather heavy boiler work so as to properly maintain the power for longer periods, some of the facilities being transferred from the back shops to the roundhouses. The back-shop forces were reduced in proportion. Prior to the change all judgment as to months good for, miles to be run between shoppings, etc. was based on the theory that locomotives were good for a term of 12 months only, and consequently a large amount of data was prepared to show that this attitude was not in keeping with the operation of the property and therefore should be adjusted to the new method. Prior to 1921 there was no specific application of the plan of assigned mileage to be used as a basis for shopping power. This method was put into use at that time and a statement prepared showing the expected mileage to be run out after each classified repair, divided according to types of power. It is important that the same mileage should not be applied to the same type of power regardless of where or how used, and in this respect an assigned mileage for each class of service, type of power, and for each division instead of for the system as a whole is necessary in practice, otherwise classified repairs will be made in roundhouses, but not so reported, in order to avoid breaking the mileage. The method of breaking mileage varies throughout the country, but this does not affect the data used here. As to the results obtained from this change of plan, it should be understood that there have been some wage and material price variations since 1920, but these adjustments account for approximately 14 per cent of the reductions attained. The cost trends on the chart merely indicate the actual reductions, with no separation between fluctuations in the cost of material and labor, shop efficiency, etc. The cost per locomotive-mile during the high-wage period of 1920 reached 34 cents when the shopping frequency was 14.28 months, but after the frequency of back shopping was reduced the cost steadily declined and in 1924 was less than 26 cents. This represents a reduction of approximately 24 per cent. The cost per tractive-effort pound was reduced from 27 cents in 1920 to 16.5 cents in 1924, or 39 per cent. The cost of repairs per locomotive owned was \$9300 in 1920 and \$6000 in 1924, or a reduction of 35 per cent. The cost per thousand tractive-effort ton-miles was reduced from 1.075 cents in 1920 to 0.676 cent in 1924 or 37 per cent. In the meantime the average size of locomotives increased 6 per cent. The method of measuring the cost of repairs per tractive-effort ton-mile was to take the tractive-effort pounds owned, reduce them to tons, multiply by the miles run in thousands, and divide this into the cost of repairs, Account 308. (This unit should not be confused with ton-miles hauled; it is entirely independent of the rate of grade or curvature and is merely the force of one ton acting parallel with the rails and at the circumference of the drivers through a distance of one mile). Expressed as an equation,

$$D = \frac{C}{\frac{A}{2000} \times \frac{B}{1000}}$$

where

A = total tractive-effort pounds owned
B = total locomotive miles run during year
C = cost of repairs, Account 308, or exclusive of depreciation, retirement, etc.
D = cost of repairs per 1000 tractive-effort ton-miles.

As previously stated, there were reductions in wage rates and cost of material in this period, so that the entire reduction is not to be credited to the change in plan referred to.

Finally, we have seen that this principle of shopping locomotives is in no sense special or peculiar. As to whether or not a policy as outlined could be taken as a criterion, it would be difficult to state. The plan was adopted for the C. M. & St. P. system because it appeared to be properly applicable. It is a matter of interest in this connection, however, to make a study of ten carriers where there is a wide range of policy, using the same units outlined above. The value of the units used cannot be considered as entirely intrinsic and for that reason the method employed should not be considered as absolute. The chart of Fig. 2 is offered as a result of a study of various carriers, some having a high-frequency and some a low-frequency method. In plotting the data, scales were used merely to throw relative items together in order to indicate those which run in a certain ratio and those which run inversely. The horizontal scale is the average tractive-effort pounds per locomotive owned—to show the size maintained. The data are based on 12 months in 1924.

Another point may be observed. In the matter of performance the average miles per locomotive run per year is given by line A. This shows a difference in performance which does not follow relatively the variation in size of power, indicating many degrees in intensity of use, etc. The mileage ranges from 20,800 to 28,500

per locomotive per year. The carrier with the largest size of power made practically the same mileage per locomotive as the one with the smallest size of power shown on the chart, whereas those administrations with locomotives of a size ranging between the two extremes made less mileage per locomotive. This may be considered an element of performance and demand characteristics of the lines involved. In this case the highest mileage was 37 per cent greater than the lowest shown.

The cost per locomotive-mile as shown by line *B* is low for the carrier having the smallest size of power, being less than 17.5 cents, and is high for the one having the largest size of power, the upper range being a little less than 30 cents per locomotive-mile.

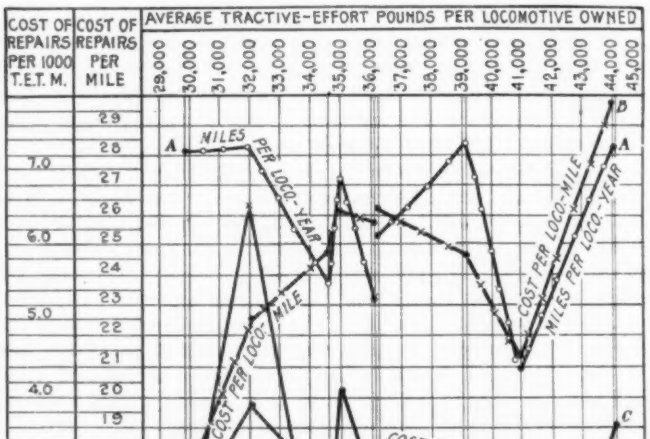

FIG. 2 COMPARISON OF COST OF MAINTAINING STEAM LOCOMOTIVES CONSIDERING AVERAGE SIZE, AVERAGE MILES, AND COST OF REPAIRS PER MILE PER TRACTIVE-EFFORT POUND AND PER 1000 TRACTIVE-EFFORT TON-MILES

The average size of power expressed in tractive-effort pounds was 47 per cent greater in the largest average size as compared with the smallest average size, whereas the cost per mile was 71 per cent greater for the larger than the smaller power, so that it may be said that in this case the cost increased one and one-half times as the unit size of power increased. This figure is not in itself entirely significant.

The cost of repairs per tractive-effort pound being a measure of size only, does not run in direct ratio with the increase in size. It will be noted that while the smallest size of power has the lowest cost of repairs, the largest size of power does not have the highest cost of repairs, both being exceeded by carriers having locomotives of intermediate capacities. The composite factor of cost of repairs per thousand tractive-effort ton-miles, consisting of the size and mileage, ran somewhat inversely with the capacity of power owned, with variations in the intermediate sizes. Here it is interesting to note that the smaller size of power cost more than the larger, the result being due in this case to the carrier with the larger power running about the same mileage per unit as the carrier with smaller power.

There would be no profit in going further into details, since these data are presented merely as a matter of comparison and to illustrate the fact that it is most difficult to establish a criterion or a specific policy which is applicable in all cases. Road characteristics, density of traffic, and many other elements must be considered in any calculation that aims to be complete and conclusive. However, in general it has been found that carriers using large-size power have a fairly high frequency of back shopping, which is of great interest in this study because it is evidence, for the most part, of intensive use and a more or less uniform power demand. Thus far the frequency has been stated in terms of time only. It is affected very largely by the rapidity with which mileage is run out, and therefore, in a general way, reflects whether carriers are long or short in their power ownership.

These data indicate that as the average tractive-effort pounds owned increases, the cost of repairs per mile increases in a rather definite way; that the average miles per locomotive run and the average cost of repairs per tractive-effort pound have the same range characteristics; and that the average cost of repairs per thousand tractive-effort ton-miles varies somewhat inversely with the average tractive-effort pounds per unit owned, with intermediate fluctuations.

In using tractive-effort ton-miles as a unit of measure in this case it should be understood that there is a variable feature in the actual amount of capacity employed as compared with the maximum available. The larger units may or may not exert as great a percentage of the total tractive effort as the smaller units, and to the extent of this variation this measure must be considered only with the knowledge thereof. Here again maximum or ruling gradients, scheduled tonnage, etc. are factors showing how near the capacity available is utilized as compared with the maximum at hand, and the studies given here are made only with the intention of indicating that, regardless of any units of measure used, there are local conditions which determine the differences in the showing made and that these are usually found to justify the outcome. The tabulations are therefore presented with the necessary reservations as to limits of their scope. This unit of measure does not include the work performed, that is, the tonnage hauled, which if added would doubtless give trends differing from those shown on the chart; but the tonnage hauled is a matter of record in freight performance only, whereas the data thus far considered apply to all classes of power. Statistics are now available to show the gross ton-miles per freight-train-hour, which is a fair measure of locomotive performance when considering the average size as well as the number of units employed. This reflects efficiency in train handling as well as corresponding utilization of power, and where there is prompt turning in roundhouse care and running repairs fewer locomotives may be used for a given traffic, thus building up a reserve and maintaining a proper shopping period. It is necessary, of course, to apply such data to road engines only, and this can be done with the information at hand. The variation among carriers in such performance is quite extreme, some having as high as 26,000 and others as low as 12,000 gross ton-miles per train-hour. This difference is far greater than the average size of power and other influencing factors such as grades, curvature, signal stops, etc. would indicate, and leaves open to study the question of greater development along the line of utilization of power and consequent shopping methods.

EFFECT OF SPECIFIC SHOPPING POLICY ON COST OF REPAIRS

Just what effect the specific policy followed has upon the trend of the cost of repairs is not thoroughly ascertainable, but it would seem that a minimum cost may be expected when it has been definitely established that a proper balance between classified and running repairs has been arrived at. No specific formula for reaching this division has yet been developed. A study of the cost of repairs per mile divided between running and classified work does not present a solution, because whenever it is necessary to decrease or increase forces and expenses, the fluctuation is felt directly in the back shop and only indirectly in the roundhouse. It is generally known, of course, that whenever it becomes necessary to curtail expenses or make reductions, it is a simple matter to close the back shops but not possible to make corresponding reductions in roundhouses because certain forces must be maintained in the latter at all times, and under such circumstances even in larger number. For that reason running-repair costs follow a more uniform trend, and the policy of the extent to which engines are given running repairs in roundhouses must be fashioned according to the relation of road time to time allowed for turning, which is largely affected by the units available for service call. Running repairs are not so directly affected by the disposition of revenues as classi-

fied repairs except where the carrier is in a position to enjoy revenues which exceed the expenses to such a degree as to constantly insure earning the net requirements. There is no argument against the great need of having uniform forces and avoiding the closing of shops, because excessive fluctuations in forces cause repair programs and the continuity of work to be disrupted, and in addition destroy discipline. Shop output is, generally speaking, directly affected by fluctuations and expenses, and this seriously affects the frequency of classified repairs.

One way of measuring performance with shop output is to compile the locomotive-miles run since last shopping, setting this up in a cumulative way monthly and comparing it with the miles restored in classified repairs. The miles restored must necessarily be based on the assigned mileage, and the balance between miles run out and restored cannot be accurately judged unless the assigned mileage is practically correct and consistent with actual performance. When the assigned mileage is set too high, then there will be more restoration of mileage reported by shop output than is actually run out; on the other hand, if the assigned mileage is too low, then the restoration is not in keeping with the run-out mileage. The experience of the C. M. & St. P. along this line has developed the fact that the application of the assigned mileage for each type of power, regardless of its use, is not sufficiently specific, and such process, when employed, needs revising by developing an assigned mileage for each type of power and for each division so that the local characteristics as to track, curvature, gradients, service, consequent tire and lateral wear, and boiler repairs can be considered as factors. Theoretically it is possible to group repairs into time cycles, but time is only one of the elements of shopping power, and as the frictional wear is mostly overcome in roundhouses the time element for shopping power resolves itself very largely into cycles based on necessity for heavy boiler repairs.

The factors used by the author's read in the general plan of shopping are assigned mileage, time, and actual physical condition based on customary and frequent inspections. Where there is a low rate or run-out mileage, time enters into the calculation to a greater degree than where mileage is run out rapidly. Physical condition is a vital element to overcome the differences in divisional characteristics or variations in the service rendered according to track, water, and other features. In addition, it can be arranged to set a limit to expenditures for the various types of power according to the class of repairs to be given, any overexpenditure to be reported and explained so that extraordinary repairs may be a matter of record. The regulation of frequency of repairs to locomotive parts is a matter of long-range study and the cycling of repairs cannot be followed specifically in all cases, although it has been the company's general policy to endeavor to follow a class No. 3 repair with a No. 4 or No. 5 and then with another No. 4 or No. 5 followed by a class No. 3, in other words, having two minor repairs between two major repairs; but this depends upon the nature of service performed and the severity as well as the rapidity with which mileage is run out. It cannot at the outset be presumed that we can obtain approximately 50 per cent of the mileage between classified repairs for the first class No. 3 repairs and then 25 per cent for each of the minor repairs, as experience has developed that inasmuch as taking up lateral, tire turnings or changes, etc. constitute a classified repair, tire and lateral wear develop and become due for renewal just as soon after a class No. 3 as after a class No. 4 or No. 5 repair; so that it is well to contemplate a distribution of the mileage and make it equal for each class of repairs, whether a No. 3, No. 4, or No. 5 class, but regulate the cost of each shopping accordingly.

A Study of Enginehouse Operation

A study of shop and roundhouse facilities cannot be summarized in terms of specific units so as to outline the direct effect upon policy and the results thereof. It involves the number of roundhouses per mile of track, the frequency of turning locomotives or the miles run between turnings, etc. As a matter of interest, it may be stated that during the time in which the change in policy referred to was taking place, studies were made of enginehouse operation not only as to repairs made but as to the cost of turning power, frequency of turning, etc. with results shown in the table immediately following.

	Transportation Expense (Not Maintenance)		
	1922	1923	1924
Average turnings per month....	53,572	59,784	54,911
Average cost per month........	$430,492	$384,969	$331,830
Average cost per engine turned.	8.30	6.44	6.04
Average cost per engine-mile, cents....................	10.25	8.35	7.68
Average miles run between turnings......................	78	77	78

No comparison can be made with other carriers in this respect because the methods of counting engines turned, the accuracy of distributing charges, the nature of roundhouse facilities, etc. vary too greatly. The above figures are merely given to show that the trend in other expenses affected by locomotives was downward the same way as indicated in Fig. 1. It is very apparent that the frequency of turning power decreases with the increase in average distance between roundhouses, and that the average miles per engine turned will increase with the spread in distance between roundhouses. This naturally involves the general study of utilization of power.

A statement of the actual hours of service per engine per day reflects the intensity of use and efficiency in turning, all of which depends largely upon the condition of power, the amount owned, and the character of maintenance. We have not been able to observe any adverse effects on the turning of engines because of decrease in frequency of back-shop repairs; it might have been assumed that so low a frequency as was developed in the change of policy would throw too much of a burden upon roundhouses for intermediate repairs and increase the hours of detention. The cost per mile of running repairs incurred in roundhouses is greater than the cost per mile of classified repairs made in the back shops, the former running rather uniformly with the number of engines turned and the latter fluctuating more in relation to increase or decrease in operating expenses because of regulating them according to revenues.

The formulation of a specific policy of back-shop attention to power, therefore, must consider a wide scope of performance, embracing the amount of property owned in relation to the demand and use thereof, the type and size of power, shop and roundhouse facilities and their relation to each other, road conditions, rapidity with which mileage is run out and restored, the ability to maintain a minimum but uniform force in back shops throughout the entire year, the ability in addition to increase the rate of repairs in the low-peak-loading months so as to have a larger supply available for service in high-peak months, the range of variation between high- and low-peak months, etc. Where back-shop and roundhouse facilities are modernized and properly regulated by means of machine tools, power plants, handling devices such as cranes, hoists, tractors, manufacturing devices and an adequate store stock, it should be possible to determine closely the final balance between classified and running repairs with its relation to the cost of performance expressed in various units of measure, some of which have been outlined above.

Bearing of Utilization of Power on Shopping Policy

The utilization of power requires careful and detailed study because any variation must of necessity have a marked bearing upon shopping policy. It has been found when comparing the performance of a greater number of carriers than used in plotting Fig. 2 that the tendency to run out locomotive-miles rapidly increases somewhat with the increase in size of power, and, as before stated, the rate at which mileage is run out is a determining factor in the proper frequency of classified repairs. There is a great variation in the mileage performance, and this reflects either good or poor power assignment and use, or a high or low density of traffic. Where the percentage of locomotives required for business is large in relation to the total ownership, where the monthly mileage is high, and where the hours of service per day are above the average of eight, this reflects a small reserve for detention in and awaiting shops, and the back-shop efficiency is then a more vital factor and the time consumed in making repairs is a greater element than where opposite conditions prevail. The average number of days out of service for the item of in and awaiting shop is not a matter of uniform record and therefore is not always available, but it is well

to make mention here of the importance of having for this purpose a detailed knowledge of the number of days locomotives are out of service. It is possible to arrive at the average days of detention in the past so as to regulate the future by the use of the following formula:

Let A = average number of locomotives in and awaiting shop per month
B = total locomotives owned
C = total days in the year and
D = frequency of shopping.

Then

$$\frac{A}{B} \times C = \text{Average number of days detention per locomotive per year}$$

and

$$\frac{A}{B} \times C \times D = \text{Number of days detention per shopping.}$$

In cases where the percentage of power in service is low as compared with the total owned it is usually found that the hours of service per day are low or approximately six, which makes it possible to have a large waiting list and to turn locomotives less rapidly through the shops and still have ample protection for service. It would be expected that where the average size of power was small there would be more units out of service than where the average size of power was large, other things being equal, but on the other hand the data supporting the chart indicate that where large power runs out mileage as rapidly as small power it incurs a greater frequency of back-shop repairs, probably due to terminal facilities not having been improved to the same extent as the motive power. With some carriers the shopping detention is serious, while with others it does not create a problem; yet the tendency should be to increase the utilization of power, and increased utilization will depend largely upon its condition and the degree of maintenance. A campaign along the lines of reducing the number of units in active service to a minimum consistent with traffic handled, based on the average miles per locomotive despatched or the average miles between locomotive turnings (enginehouse operation) will necessarily avoid the purchase of new equipment for the purpose of increasing the complement, because when longer runs are installed and fewer locomotives are used for a given service, this naturally builds up a surplus. With a surplus of power the shopping problem is less acute. Where the gross ton-miles per train-hour indicate a slow movement in a territory where traffic is dense, trains should not be delayed because of short runs made by locomotives and frequent delays due to changing power. Movement in this case requires acceleration, and to overcome this trouble it is necessary not only to increase the length of locomotive runs but to eliminate intermediate terminals and classify trains so that the local service will be confined to the fewest possible trains, permitting a greater number to proceed without such interruption. Intensive service requires a revision of the method of repairs, and in some cases calls for a higher standard of repairs than where more locomotives are used in the same service. The objective should be to get more locomotive-miles per month out of fewer active locomotives and more hours of service per day out of each locomotive; then other factors will naturally increase the gross ton-miles per train-hour.

Turning to the problem of the time element applied to locomotive output, where orders are issued to shops for locomotives of a certain character to be made ready for service on short notice, the time factor, as regulating the date of delivery, is very often a matter of supreme importance. A study of this question very soon brings to light an intricate problem with which supervisors and others in authority have to grapple. One of the outstanding factors is that of the machine-tool and material-handling equipment, with which is identified the means of producing work rapidly and to the best advantage. Many of the latest machine tools, cranes, tractors, etc. are conspicuous for the facility with which they can be operated, the controls being conveniently placed, thus saving time in setting up and subsequently handling the machines. Another equally vital point is that of the organization of the work, which must, if time is to be saved, be planned on a definite and progressive system. All these measures are applicable to old as well as to the most modern new shops; however, they are likely to lose much of their value unless the workmen themselves coöperate in the avoidance of time wastage. Slackness in commencing work when first arriving at the shops or in resuming after an interval may result in an aggregate representing a very considerable loss of time, and make it difficult or impossible to get the engines completed to schedule. Similarly, stopping unnecessarily soon each day before the whistle blows, if indulged in on anything like a wide scale, must necessarily reduce the effective value of the working day. Piece-work and unit-output-measure systems are designed to make such action on the part of the workmen unprofitable to them, but even where these are in force it is often found impossible to correct the loss. It is therefore only through the strict coöperation of every one concerned, combined with proper shop systems and the use of tools and facilities fully adapted to their purpose, that rapidity of production can be assured.

Conclusion

One point of serious practical importance remains, namely, that the designated mechanical officer should place before his executive a practical and sound analysis of the requirements for the upkeep of motive power, shops, power plants, and tool equipment, and recommendations for expansion or rehabilitation to save against existing unit expense known to be out of keeping with the possibilities for best achievement. It is also desirable to view the problem from the standpoint of (1) Performance, (2) Cost, and (3) Progress.

In making submissions for proposed expenditures they may be grouped under items or savings as dealing with:

1 Fuel
2 Labor
3 Materials
4 Delay to Train Movements
5 Accident Prevention or Personal Injury.

Once we have grasped these fundamental facts, we can promptly get rid of not a few popular fallacies already referred to. It is regrettable and not a little surprising that in fixing ordinary running expense and upkeep the budget allowance to be approved by any administration should fail to be based upon the requirements as made necessary because of traffic or operating conditions and complying with a general policy formulated to properly care for conditions in the most effective and economical manner, and not altered to fluctuate with current temporary drops in traffic, which are often seasonal. Where there is an increase or decrease in business handled during a long period it is necessary to modify the assignment of forces employed in such a way as will permit of increasing forces economically, that is, gradually, if materials and facilities are in readiness to absorb the advantage of greater forces to be employed, and to decrease them without permitting the property to depreciate or build up deferred maintenance. Such changes in the budget should never be made without the most careful consideration of all phases of the problem, based on considerations of a broad policy. For instance, during the course of five or ten years the traffic on a given property may warrant certain expenditures for maintenance of locomotives, shops, power plants, tool equipment, and new locomotives; this expenditure should be made constantly each and every year. The policy of trying to maintain an even or favorable allocated net earning capacity each month, regardless of the business handled, in order to save against financial fluctuations as to credit or stock issues, acts to cause a considerable influence to make administration difficult, particularly during low seasonal movements. An accumulative allocated net trend, with a full knowledge of balances between losses and gains, should permit of a more even flow of maintenance work. Unless this is done a stable policy cannot readily be worked out or maximum economy obtained with a minimum outlay for facilities and for labor. What should be arrived at is a reasonable maintenance standard for the property as a whole. The basis should be gaged from a consideration of the general earning capacity and also upon the kind and class of traffic handled. With this part correctly fixed, slight fluctuations in business should not materially alter the yearly progress as applied each month with the view toward stability of employment and proper discipline and administration of the work. In a large sense the motive-power man is only as successful as his management will let him be. This is one

of the reasons why so many able men have left the railroad service for other and more productive fields. Every motive-power man of wide experience knows what a lack of executive support or full coöperation means. The best policy on earth avails little if it does not have support from the top of the organization down. Too many of our executives judge the mechanical man by locomotive-miles produced without any direct reference to work done by the locomotives, which is a vital factor. It is for this reason that data was presented here to indicate not only mileage performance, but a composite factor of mileage and size or capacity.

One other point in conclusion: It has frequently proved to be the case that, regardless of all of the devices and methods employed to increase the efficiency of power, the personnel and organization employed are the most important in this respect. There is a great difference of opinion as to whether or not a locomotive is due for shopping. Judgment in this respect varies, but the basis depends largely upon training and the policy adopted, whether expressed or implied. The psychology of high or low frequency varies. The human factor in shopping policy is as vital as the material factor.

Analysis of Power-Plant Performance Based on the Second Law of Thermodynamics

Details of a Step-by-Step Method of Analyzing Power-Plant Performance That Shows the Losses of Available Energy Occurring in Each Stage of the Process

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IT IS customary to analyze power-plant performance by preparing a heat balance based on the first law of thermodynamics to show the distribution of the heat of combustion of the fuel. The object of operating a power plant, however, is not to distribute heat but to convert heat into mechanical work. An analysis based upon the second law of thermodynamics is therefore much more enlightening than the usual first-law heat balance, because such an analysis shows the lost opportunity for converting heat into mechanical work due to the imperfections in each stage of the process.

Before presenting such an analysis, some remarks will be made upon the second law of thermodynamics. These remarks are believed to be in order since engineers apparently have such a hazy idea of the meaning of the second law. The first law can be stated in very simple words, such as:

> Heat and mechanical work are different forms of energy, and when one is converted into the other, the ratio is 778 ft-lb. to 1 B.t.u.

The same brevity has been attempted in stating the second law, with the result that this law has generally been a jingle of words rather than a working tool. In order to present a definite conception of the second law which will enable it to be used as the basis for an analysis of power-plant performance, some very elementary principles will first be stated.

To do mechanical work it is necessary to exert a force through a distance, because work is so defined. The addition of heat to a solid body or to a fluid generally expands the substance, even against considerable resistance. The mechanical work thus performed is equivalent to a greater or less proportion of the heat added. With isothermal expansion of air under moderate pressures, for example, practically 100 per cent of the heat added is converted into mechanical work. The idea that such a thing is impossible is one widespread misconception of the second law. The second law of thermodynamics, however, does not apply to this case, but only to cases where the same medium must be used over and over again.

Under this limitation it is impossible on this earth to convert into mechanical work 100 per cent of the heat supplied for the reason that some heat must be rejected by the working substance to contract it in order that it may again be expanded in using it the second time. To expand the working substance there must be a "source of heat" at a higher temperature than the working substance; and to contract the working substance there must be a "source of cold" at a lower temperature. By bringing the working substance alternately into contact with the "source of heat" and the "source of cold," mechanical work may be performed equivalent to the difference between the heat supplied from the source of heat and that rejected to the source of cold.

As shown by Carnot, there is a certain maximum ratio of the heat converted into mechanical work to that supplied from the source of heat, which ratio is the efficiency of a perfect engine. This ratio is a function of the upper and lower temperatures only, and is independent of the nature of the working substance used in the perfect engine. The Carnot cycle shows theoretically how this perfect engine must operate. The Stirling cycle shows another method of attaining the maximum efficiency, but a working substance with certain specific-heat relations is required.

From textbooks on thermodynamics, the following mathematical expressions may be obtained for the maximum possible conversion of heat into mechanical work and the corresponding minimum rejection of heat to the source of cold with the Carnot cycle. Calling these quantities the "available energy" and "unavailable energy," respectively, we have

$$\text{Available energy, } dW = \frac{T - T_0}{T}\,dQ = (T - T_0)dS \quad [1]$$

$$\text{Unavailable energy, } dQ_0 = \frac{T_0}{T}\,dQ = T_0\,dS \quad [2]$$

where T = absolute temperature of the source of heat
T_0 = absolute temperature of the source of cold
dQ = heat supplied at temperature T to the working substance in a perfect engine
dQ_0 = heat rejected at temperature T_c by the working substance in a perfect engine
dW = heat converted into mechanical work by a perfect engine, and
dS = dQ/T, by definition the change in entropy of the material source of heat.

These mathematical relations express the second law of thermodynamics for which the following statement is proposed:

> When a medium is used to convert heat into mechanical work by operating in a closed cycle between an upper absolute temperature T and a lower absolute temperature T_0, only a portion of the heat supplied at the upper temperature can be converted into mechanical work when the lower temperature is above absolute zero; and the relation between the heat supplied at the upper temperature dQ, the maximum quantity available for conversion into mechanical work dW, and the minimum quantity rejected at the lower temperature dQ_0, is given by

$$\frac{dQ}{T} = \frac{dW}{T - T_0} = \frac{dQ_0}{T_0} \quad [3]$$

This relation also applies to the reverse operation, but we are not at present concerned with refrigerating machines.

Based on this statement of the second law of thermodynamics, it is possible to analyze the performance of a power plant step by step and tabulate the losses of available energy occurring in each stage of the process. In explaining this analysis to classes in thermodynamics, the greatest difficulty encountered has been to get the students to understand that the perfect engine of Carnot or Stirling is applied simply as a measuring rod at each step of the process, none of the fluids in the power plant analyzed being the medium used in the perfect engine. The underlying conceptions for this analysis are: (a) A perfect engine is assumed to be operated by heat supplied from each of the actual fluids in turn, furnace gases, steam, etc. at each step in the process; (b) The temperature of heat supply will vary according to the change in temperature which would be experienced by the fluid in question giving up its heat to the perfect engine; (c) The temperature of exhaust of the perfect engine will be constant and equal to that of the atmosphere or of the water available for condensing purposes.

In applying relations [1] and [2] to determine the available energy and the unavailable energy at any step in the process, the calculations are very simple when steam is the source of heat to the perfect engine because the entropies of steam are tabulated. In this case, by integration of [2] we have

$$\text{Unavailable energy, } Q_0 = T_0(S_1 - S_2) \quad [4]$$

$$\text{Available energy, } W = Q - Q_0 \quad [5]$$

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where S_1 and S_2 are the entropies of the steam at the beginning and end, respectively, of the withdrawal of heat which is supplied to the perfect engine.

For the furnace gases, of which the entropies are not known, Formula [2] may be integrated by using the relation

$$dQ = (a + bT)dT \qquad [6]$$

where a and b are the specific-heat coefficients. Relation [6] may be integrated to obtain the heat supplied by the furnace gases in cooling from T_1 to T_2, namely,

$$\text{Energy supplied, } Q = a(T_1 - T_2) + \frac{b}{2}(T_1^2 - T_2^2) \qquad [7]$$

$$= \left[a + \frac{b}{2}(T_1 + T_2)\right](T_1 - T_2) \qquad [7a]$$

Integrating [2] with the aid of [6], we have

$$\text{Unavailable energy, } Q_0 = aT_0 \log_e \frac{T_1}{T_2} + bT_0(T_1 - T_2) \qquad [8]$$

$$\text{Available energy, } W = Q - Q_0 \qquad [9]$$

When the specific heat may be assumed constant with a sufficient degree of accuracy, Formulas [7] and [9] reduce to

$$\text{Energy supplied, } Q = a(T_1 - T_2) \qquad [10]$$

$$\text{Unavailable energy, } Q_0 = aT_0 \log_e \frac{T_1}{T_2} \qquad [11]$$

$$\text{Available energy, } W = Q - Q_0 \qquad [12]$$

The calculations for unavailable energy are simpler than for available energy; and as the change in unavailable energy for any stage of the process must equal the change in available energy, the former is generally calculated in preference to the latter.

As an example of the application of the second law of thermodynamics enunciated above, the performance of a locomotive will be analyzed, the following data being taken from Pa. R.R. Bulletin 28, for test No. 3925 of Mikado type locomotive, Pa. Class L1s:

Heating value of coal	14,044 B.t.u. per lb. of dry coal
Temperature in firebox	2490 deg. fahr.
Temperature in smokebox	494 deg. fahr.
Temperature of feedwater	70 deg. fahr.
Temperature of superheated steam in branch pipe	555 deg. fahr.
Temperature in exhaust pipe	263.1 deg. fahr.
Atmospheric pressure	14.2 lb. per sq. in.
Steam pressure in branch pipe	193.7 lb. gage, say, 208 lb. per sq. in. abs.
Pressure in exhaust passage	8.2 lb. gage, or 22.4 lb. per sq. in. abs.
Dry coal fired per sq. ft. of grate surface	86.6 lb. per hr.
Steam to engines per lb. of dry coal fired	7.03 lb.
Steam per indicated horsepower	18.2 lb. per hr.

The calculations for the ordinary heat balance based on the first law will first be made:

1297.4 B.t.u. per lb. total heat of superheated steam from steam tables

38.1 B.t.u. per lb. heat in feedwater from steam tables

$1297.4 - 38.1 = 1{,}259.3$ B.t.u. to produce one lb. of steam

$1259.3 \times 7.03 = 8853$ B.t.u. transmitted to the steam per lb. of dry coal.

For a temperature of 2490 deg. fahr. in the fuel bed and a heating surface temperature of, say, 390 deg. fahr., we have

$$1600\left[\left(\frac{460 + 2490}{1000}\right)^4 - \left(\frac{(460 + 390}{1000}\right)^4\right] =$$

$1600\,(75.74 - 0.52) = 120{,}350$ B.t.u. per hr. per sq. ft. of grate surface radiated from the fuel bed to the heating surface

$\dfrac{120{,}350}{86.6} = 1390$ B.t.u. per lb. of dry coal reaches the heating surface by radiation

$8853 - 1390 = 7463$ B.t.u. per lb. of dry coal reaches the heating surface by convection.

Assume the specific heat of the products of combustion to be given by $0.24 + 0.00002\,T$, where T is the absolute temperature in degrees fahrenheit. The mean specific heat between T_1 and T_2 is then given by $0.24 + 0.00001\,(T_1 + T_2)$ B.t.u. per lb., or according to Formula [7a],

$[0.24 + 0.00001\,(460 + 2490 + 460 + 494)](2490 - 494) = 0.279 \times 1996 = 556.9$ B.t.u. per lb. of products of combustion given up to heating surface

$\dfrac{7463}{556.9} = 13.40$ lb. of products of combustion per lb. of dry coal.

$[0.24 + 0.00001(460 + 494 + 460 + 70)](494 - 70) = 0.225 \times 424 = 108.1$ B.t.u. in stack gases per lb. of gases

$108.1 \times 13.40 = 1449$ B.t.u. in stack gases per lb. of dry coal

$8853 + 1449 = 10{,}302$ B.t.u. per lb. of dry coal produced by combustion

$14{,}044 - 10{,}302 = 3742$ B.t.u. per lb. of dry coal lost by unburnt fuel, incomplete combustion, etc.

$\dfrac{18.2}{7.03} = 2.59$ lb. of dry coal per hr. burned per indicated horsepower

$\dfrac{2546}{2.59} = 983$ B.t.u. converted into mechanical work per lb. of dry coal

$8853 - 983 = 7870$ B.t.u. in exhaust steam per lb. of dry coal

$\dfrac{7870}{7.03} = 1119$ B.t.u. per lb. of exhaust steam above 70 deg. fahr.

$1119 + 38 = 1157$ B.t.u. per lb. total heat of exhaust steam

$202.2 + x \times 957.8 = 1157$, whence $x = 0.997$ = dryness fraction of exhaust steam.

NOTE: The temperature in the exhaust pipe was 263.1 deg. fahr. by measurement, thus indicating 29 deg. of superheat. It is therefore probable that the superheat in the steam initially was greater than measured. To be consistent, however, the exhaust steam will be assumed to have the quality calculated.

FIRST-LAW BALANCE

	B.t.u.	Per cent
Heat lost by unburnt coal, etc.	3,742	26.7
Heat lost in stack gases	1,449	10.3
Heat converted into work	983	7.0
Heat rejected in exhaust steam	7,870	56.0
Heating value of dry coal	14,044	100.0

Calculations for the second-law balance will now be made of available energy and unavailable energy at each step of the process in order to determine the loss in available energy, or gain in unavailable energy, during each stage. We shall assume the lower temperature to be that of the feedwater, 70 deg. fahr. (530 deg. abs.)

During the first stage of the process, namely, the combustion of the fuel, the 3742 B.t.u. per lb. of dry coal not produced by reason of unburnt coal, incomplete combustion, etc. is evidently unavailable for conversion into mechanical work.

Of the 10,302 B.t.u. per lb. of dry coal resulting from combustion, 1390 B.t.u. are radiated from the fuel bed at the constant temperature of 2490 deg. fahr. From Formula [2],

$1390 \times \dfrac{460 + 70}{460 + 2490} = 1390 \times 0.1797 = 250$ B.t.u. per lb. of dry coal unavailable portion of radiant heat.

$1390 - 250 = 1140$ B.t.u. per lb. of dry coal available portion of radiant heat.

The remainder of the 10,302 B.t.u., namely, 8912 B.t.u. per lb. of dry coal, reaches the heating surfaces by convection of the furnace gases. That is, this heat leaves the furnace in 13.40 lb. of products of combustion at 2490 deg. fahr. (2950 deg. abs.). Substituting in Formula [8] under the assumption that these gases are cooled to 70 deg. fahr. by imparting their heat to operate a perfect engine, we have

$$530\left[0.24 \log_e \frac{2950}{530} + 0.00002\,(2950 - 530)\right] =$$

$530 \times 0.4604 = 244.0$ B.t.u. unavailable energy per lb. of furnace gases

$13.40 \times 244.0 = 3270$ B.t.u. unavailable energy in furnace gases per lb. of dry coal

$8912 - 3270 = 5642$ B.t.u. per lb. of dry coal available in firebox gases for transformation into mechanical work by a perfect heat engine.

These products of combustion escape to the smokebox at a tem-

perature of 494 deg. fahr. (954 deg. abs.) and have a sensible heat above 70 deg. fahr. of 1449 B.t.u. per lb. of dry coal. Substituting in Formula [8],

$$530\left[0.24 \log_e \frac{954}{530} + 0.00002(494 - 70)\right] = 530 \times 0.1496$$

= 79.29 B.t.u. unavailable per lb. of smokebox gases

13.40 × 79.29 = 1062 B.t.u. per lb. of dry coal unavailable energy in smokebox gases

1449 − 1062 = 387 B.t.u. per lb. of dry coal available energy in smokebox gases, but lost with these gases passing out the stack.

Of the 10,302 B.t.u. per lb. of dry coal resulting from combustion, therefore,

1140 + 5642 = 6782 B.t.u. per lb. of dry coal are available for conversion into mechanical work by a perfect engine.

But 387 B.t.u. of this available energy are lost with the escape of the products of combustion out of the stack. Hence, of the heat transferred to the steam,

6782 − 387 = 6395 B.t.u. per lb. of dry coal were available for conversion into mechanical work by a perfect engine before the transmission of heat through the heating surface.

To find the availability of the 8853 B.t.u. per lb. of dry coal transmitted through the heating surface after its transmission, we obtain from steam tables:

1.6486 entropy per lb. of superheated steam and
0.0746 entropy per lb. of water at 70 deg. fahr.
Substituting in Formula [4],

530(1.6486 − 0.0746) = 834.2 B.t.u. unavailable per lb. of steam

7.03 × 834.2 = 5864 B.t.u. per lb. of dry coal unavailable energy in the superheated steam

8853 − 5864 = 2989 B.t.u. per lb. of dry coal are available for conversion into mechanical work by a perfect engine after transmission through the heating surface

6395 − 2989 = 3406 B.t.u. per lb. of dry coal loss of available energy due to heat transfer in the boiler.

Now, for the exhaust steam, we have from the steam tables corresponding to the quality previously determined,

1.7293 − 0.003 × 1.3809 = 1.7252 entropy per lb.

Substituting in Formula [4],

530(1.7252 − 0.0746) = 874.8 B.t.u. unavailable per lb. of steam.

7.03 × 874.8 = 6150 B.t.u. per lb. of dry coal unavailable energy in exhaust steam.

Since the exhaust steam contains 7870 B.t.u. per lb. of dry coal (above water at 70 deg. fahr.) according to previous calculations, we have

7870 − 6150 = 1720 B.t.u. per lb. of dry coal available for conversion into mechanical work by a perfect engine, but carried out by the exhaust steam.

Since 2989 B.t.u. per lb. of dry coal were available in the steam entering the engine and 983 B.t.u. per lb. of dry coal are equivalent to the work actually done, we have

2989 − 983 − 1720 = 286 B.t.u. per lb. of dry coal loss of available energy due to imperfections in the engine cylinders.

It may be noted that if the engine cylinders had been less imperfect in their operation, the available energy lost in the exhaust steam would have been somewhat less. The possibility of improvement in the engine cylinders is therefore somewhat greater than the figure 286 would indicate.

Summing up the losses of available energy, we obtain

SECOND-LAW BALANCE

	B.t.u.	Per cent
Unavailable due to unburnt fuel, etc.	3,742	26.6
Unavailable part of radiant energy	250	1.8
Unavailable energy in firebox gases	3,270	23.3
Available energy lost in smokebox gases	387	2.8
Available energy lost by heat transfer	3,406	24.2
Heat transformed into work	983	7.0
Available energy lost by imperfections in cylinders	286	2.0
Available energy lost in exhaust	1,720	12.3
Heating value of dry coal	14,044	100.0

Comparing the first-law balance with the second-law balance, we find some items appearing in the latter which do not occur in the former, while other items are greatly altered in their relative proportions. Thus, one of the largest losses appearing in the second-law balance is that due to heat transfer in the boiler, amounting to nearly one-quarter of the heating value of the fuel. This is the loss that is now being successfully attacked and reduced by the use of higher steam pressures and other fluids than water, such as mercury.

The loss in the exhaust steam appears reduced from over one-half of the heating value of the fuel in the first-law balance to less than one-eighth in the second-law balance, which is its correct relative importance. In an analysis of a condensing plant the loss in the exhaust is a still lower portion of the heating value of the fuel, thus indicating the gain due to the use of condensers.

In calculating the second-law losses during combustion, various assumptions might be made in order to prorate these losses among unburnt fuel, incomplete combustion, excess air, etc. and in certain cases it will be desirable to attempt such a division. The order in which the calculations are made, however, will affect the prorating. In many cases the simple expedient adopted in these calculations will suffice.

In presenting the second-law analysis for the first time, a simple case has been chosen for illustration, namely, a locomotive. No great difficulties, however, will be encountered in applying this analysis to more complicated power systems. While somewhat more complicated calculations are required for the second-law balance than for the usual first-law balance, it is believed that the facts revealed thereby will more than justify its extended use.

In closing, the author wishes to acknowledge his indebtedness for the general idea of preparing a second-law balance to Dr. R. C. Tolman, of the California Institute of Technology.

A Microscopic Study of Pulverized Coal

Results Showing That Screen Tests for Fineness May be Misleading in Making Comparisons of Pulverizing Mills

BY L. V. ANDREWS,[1] WORCESTER, MASS.

THE usual expression of the fineness of pulverized coal is given as the percentages of the sample passing through standard 100-mesh or 200-mesh screens. It is commonly assumed that pulverized coal of which 95 per cent will pass through a 100-mesh screen and 85 per cent through a 200 mesh screen, is suitable for all practical purposes, although considerable deviation is allowed from these percentages in current practice.

This method of specifying pulverized coal is not necessarily indicative of the quality of such coal with respect to fineness; i.e., one sample of pulverized coal testing 85 per cent through a 200-mesh screen may be entirely different from another sample testing to the same percentage through a 200-mesh screen, when the fines distribution below 200-mesh are considered.

As an illustration, mix two samples of pulverized coal. For sample No. 1 let the mixture have the following proportions by weight:

All through 60 mesh and on 100 mesh	5 per cent
All through 100 mesh and on 200 mesh	10 per cent
All through 200 mesh and on 250 mesh	85 per cent

and for sample No. 2 make the following mixture:

All through 60 mesh and on 100 mesh	5 per cent
All through 100 mesh and on 200 mesh	10 per cent
All through 1000 mesh and on 1200 mesh	85 per cent

It must be admitted that sample No. 2 would be much better for burning, from a combustion standpoint, than sample No. 1, for in all cases the finer coal will ignite more readily and burn more completely than coarser coal, assuming that the other factors relating to combustion are equal.

If the customary screen tests were run on these samples, the same results would be shown for both: namely, 95 per cent through a 100-mesh screen and 85 per cent through a 200-mesh screen.

It is obvious, then, that merely testing by the two standard screens will not indicate the quality of coal with respect to fineness unless there is a uniform graduation, or rather a similar gradation of the size of particles from the coarsest to finest in the samples being tested.

Types of Pulverizers

It is not readily conceivable that the two dozen or more pulverizers on the market in the United States today will give the same proportionate graduation in fineness, especially when the numerous distinct types of machines are considered with reference to grinding action and the further segregation due to different methods by which pulverized material is removed from the machine.

Considering pulverizing actions only, there are four distinct types of pulverizers in common use, a fifth which has been tried out quite thoroughly in at least two instances, and possibly others of which no information has been secured. These are classified as follows:

Contact Mills. In this class are listed all the mills in which the coal is ground in a thin sheet or ribbon between two elements which have a rolling action with respect to each other, and which consist of a circular bull ring as one element, within which are revolving balls or rollers comprising the second element. The two elements are forced together by the action of centrifugal force or powerful springs, thus crushing any material which is introduced between them.

Tube and Ball Mills. This type employs as grinding members either tubes, rods, or balls, or combinations of these, forming one element, contained in a horizontal revolving cylinder which comprises the second element. Pulverization is accomplished by the tumbling action of these tubes, rods, or balls when the cylinder is set in motion, and takes place between the members comprising the first element as well as between these and the shell of the revolving cylinder.

Impact Mills. In this class are all the new types of unit pulverizers so rapidly gaining in favor which employ as primary grinding elements high-speed paddles, pegs, or hammers which shatter the coal particles by striking them at high speed or by hurling the particles violently against each other or against stationary liners, corrugations, or pegs, which may be considered as secondary elements.

Attrition Mills. In this class are machines employing a rubbing action between the grinding surfaces. This type is not in general use for powdered-coal preparation.

Roll Mills, No Contact. In this type of mill pulverizing is done by passing a ribbon of coal between rolls which crush it between them in a manner similar to that used for grinding wheat to make flour. This type of mill has not proven generally successful for fine coal grinding.

Microscopic Examination of Samples

Inasmuch as power must be expended for grinding in a pulverizer of any character, it is obvious that less power will be consumed if the material be removed just as soon as it attains the specified fineness instead of remaining in the pulverizer until reaching a greater fineness. This leads to considering the necessity for determining accurately the fineness of product before passing judgment on the merits of a pulverizer based on power consumption per unit of material ground. Inasmuch as there is a reasonable possibility that the standard screen tests are not accurate enough, it should be determined whether or not there is a uniform gradation of fines among the samples from pulverizers of which there is more or less accurate information.

The best way actually to visualize any difference which may be present is to examine each sample under the microscope, making a note of the proportionate quantity of extreme fines to that of the coarsest in the sample being examined.

Photomicrographs of several samples are shown below and a careful examination of them will verify the conclusions reached, but they do not show up as distinctly as the original slides, due to the impossibility of photographing and printing them with the same sharpness as revealed to the naked eye.

Preparation of Samples for the Microscope

The following precautions should be taken in the preparation of similar studies if results of a reliable character are to be obtained:

a Extreme care must be taken in the making of the microscopic slides to secure uniform preparation conditions so that the results may be comparable.

b A magnification must be used sufficient to show the 200-mesh particles distinctly.

c Diffused, transmitted light is best to bring out as much contrast as possible and to prevent refraction of the light from the coal particles, which gives an erroneous impression of both the size and shape.

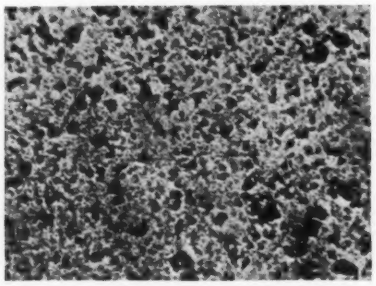
d Provision must be made for some means whereby the size of the particles may be measured or whereby a comparison of sizes may be made in different pictures.

e Some liquid must be used to hold the particles in suspension and prevent the fines from accumulating in masses which resemble large particles.

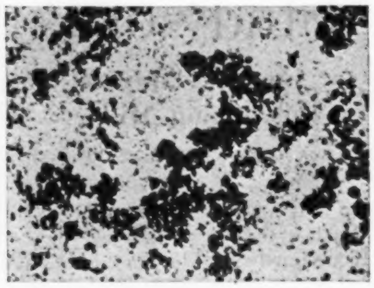
f A careful selection of a field of view must be made in each case so that all the photographs may show a uniform density of particles distribution, thereby making the photographs visually comparable.

[1] Development Dept. of Riley Stoker Corp.

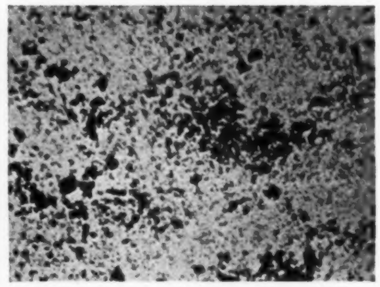
Contributed by the Fuels Division for presentation at the Spring Meeting, Milwaukee, Wis., May 18 to 21, 1925, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. All papers are subject to revision.



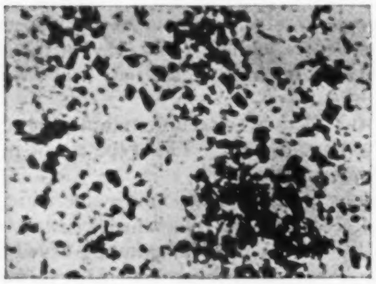
No. 1 Through 100 mesh, 98 per cent; through 200 mesh, 83.6 per cent; moisture, (approx.) 1.5 per cent.



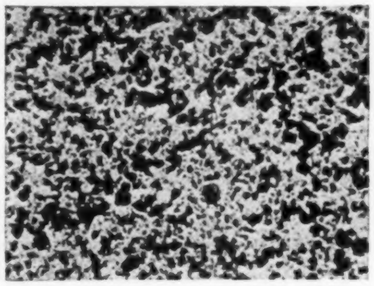
No. 2 Through 100 mesh, 95 per cent; through 200 mesh, 73 per cent; moisture, (approx.) 1.25 per cent.



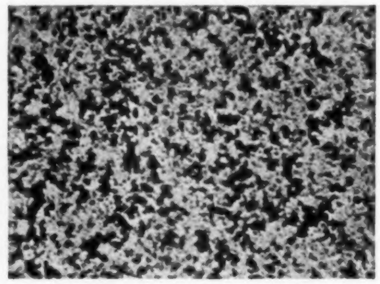
No. 3 (Previously screened to 100 mesh.) Through 100 mesh, 100 per cent; through 200 mesh, 75.4 per cent; moisture, (approx.) 6 per cent.



No. 4 Through 100 mesh, 62.4 per cent; through 200 mesh, 34.4 per cent; moisture, not obtained.

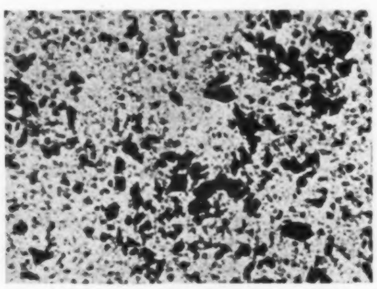


No. 5 Through 100 mesh, 75.2 per cent; through 200 mesh, 52.2 per cent; moisture, (approx.) 0.43 per cent.

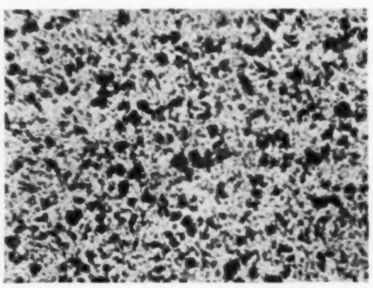


No. 6 Through 100 mesh, 93 per cent; through 200 mesh, 76 per cent; moisture, (approx.) 0.92 per cent.

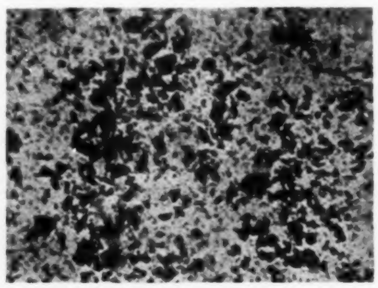
Photomicrographs of Samples Ground in Contact Mills (Magnification × 50)



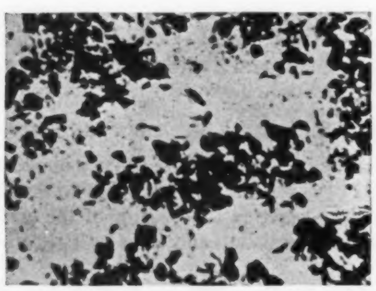
No. 7 Through 100 mesh, 98.6 per cent; through 200 mesh, 91.2 per cent; moisture entering pulverizer, 2.23 per cent; moisture leaving pulverizer, 0.7 per cent.



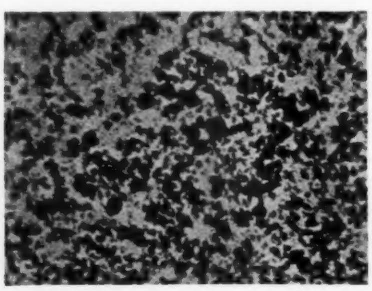
No. 8 Through 100 mesh, 98 per cent; through 200 mesh, 85 per cent; moisture, not given.



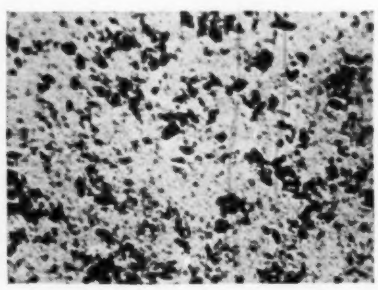
No. 9 Through 100 mesh, 94 per cent; through 200 mesh, 49.4 per cent; moisture, (approx.) 5.5 per cent.



No. 10 Through 100 mesh, 100 per cent; through 200 mesh 47 per cent; moisture, (approx.) 3 per cent.



No. 11 Through 100 mesh, 93.56 per cent; through 200 mesh, 61.3 per cent; moisture, not given.



No. 12 (Not supplied as pulverized coal.) Through 100 mesh, 30 per cent; through 200 mesh, 17.4 per cent; moisture, 6 to 8 per cent.

Photomicrographs of Samples Ground in Impact Mills (Magnification × 50)

It was found that Canada balsam separated the particles of coal well enough for all practical purposes and assisted greatly in the slide preparation because of its adhesive qualities. The method of slide preparation was as follows:

A drop of balsam was placed in the center of the slide and the cover glass was lowered upon this, thus spreading the drop of balsam evenly, after which the cover glass was slipped off the slide and laid aside until again needed. A frame 3 in. square covered with 200-mesh screen silk was then placed over the slide, being supported so that the screen lay approximately 1 in. above the glass. A small amount of coal could then be worked over the screen and an even film would be deposited in the balsam on the slide. The cover glass was then held with the balsam-coated side up and a small drop of balsam was added to the center, after which the glass was turned over and deposited on the slide. The spreading of this last drop of balsam excluded the air, thus preventing bubbles. The cover glass was then slipped around over the slide by a slight rotary movement which segregated the particles of coal to the desired density of field.

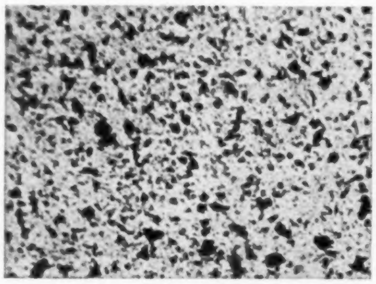
In making the photographs care was taken to select fields of view having as nearly as possible the same coarse-particle distribution, and three sets of prints were made from the negatives so that a

set of prints could be had having, as nearly as possible, a print shade common to all.

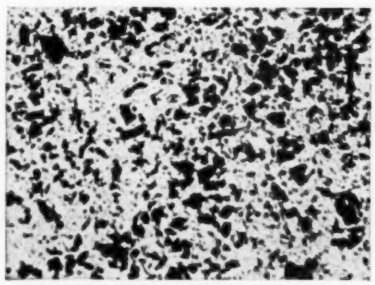
The accompanying photomicrographs are classified according to type of grinding action as previously described and are given a prefix number which denotes the sample number to distinguish it from samples produced by other mills of the same type. These photomicrographs were taken at a magnification of 50 diameters with transmitted light, and show only 200-mesh and finer material. They were prepared by the Norton Company Research Laboratory from slides furnished to them by the author.

Study of the Photomicrographs

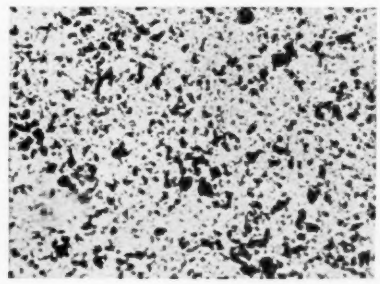
Screen tests are given for all samples except that from the roll mill, no-contact type. The only sample at hand from this mill had been formerly screened to 100 mesh, but was too small to admit of accurate screen testing. The samples obtained from a few other mills were also too small to admit of accurate screen testing, but the manufacturers obligingly furnished the figures as listed with the samples.



No. 13 Through 100 mesh, 88.8 per cent; through 200 mesh, 66.8 per cent; moisture, (approx.) 0.50 per cent.

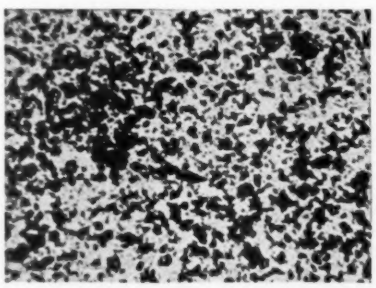


No. 14 Through 100 mesh, 65 per cent; through 200 mesh, 40 per cent; moisture, not given.

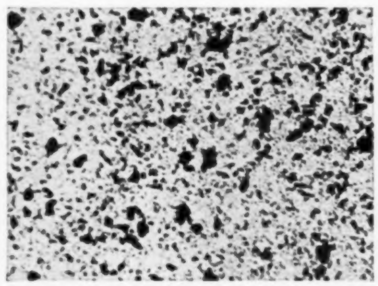


No. 15 Through 100 mesh, 83.4 per cent; through 200 mesh, 62.5 per cent; moisture, not given.

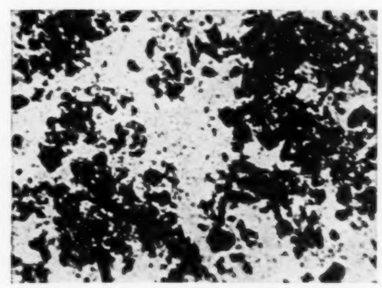
Photomicrographs of Samples Ground in Tube and Ball Mills (Magnification × 50)



No. 16 Impact Mill. Through 100 mesh, 100 per cent; through 200 mesh, 66.6 per cent; moisture, not given.



No. 17 Attrition Mill. Through 100 mesh, 100 per cent; through 200 mesh, 89.6 per cent; moisture, not given.



No. 18 Roll Mill, No Contact. Moisture, not given.

Photomicrographs of Samples Ground in Other Types of Mills (Magnification × 50)

(These samples had been screened to 100 mesh previously.)

An examination of these pictures shows distinctly that there is a wide range of difference in fineness below 200 mesh in the samples examined. Particular attention is called to sample No. 4, impact mill, and to sample No. 1, attrition mill. In sample No. 4, impact mill, scarcely any extreme fines are observable, while in sample No. 1, attrition mill, the major portion consists of extremely fine particles. However, this effect is shown to a greater or less extent by the standard screen tests. Both of the samples show 100 per cent through 100 mesh, but the impact mill shows only 47 per cent through 200 mesh while the attrition mill shows 89.6 per cent through 200 mesh.

An examination of the photographs of sample No. 1, contact mill, and sample No. 2, impact mill, shows almost identical fines distribution, and these samples are comparable by the screen tests, both showing 98 per cent through 100 mesh and practically the same through 200 mesh; the contact mill showing 83.6 per cent and the impact mill 85 per cent.

These two comparisons would indicate that a screen test was reliable. However, sample No. 1, tube and ball mill, is practically the same in appearance, although its screen test shows only 66.8 per cent through 200 mesh. This sample shows a great deal more fines than does sample No. 2, contact mill, a screen test of which would indicate a much better grade of product, as it gives 95 per cent through 100 and 73 per cent through 200 mesh.

By going a step further an attempt may be made to reconcile the photographs with the results indicated by the screen tests. Assuming that all the coal samples had been screened through 100 mesh, then the percentage through 200 mesh should indicate the effectiveness of grinding with respect to fines below 200 mesh, and it would be expected that the lower the percentage through 200 mesh, the coarser would be field shown in the photographs.

The following table shows the percentage of 100-mesh material of each sample which would go through 200 mesh:

Place	Sample No.	Per cent through 200 mesh
1	1—Impact Mill	92.5
2	1—Attrition Mill	89.6
3	2—Impact Mill	86.8
4	1—Contact Mill	85.5
5	6—Contact Mill	81.7
6	2—Contact Mill	76.8
7	3—Contact Mill	75.4
8	1—Tube and Ball Mill	75.2
9	2B—Tube and Ball Mill	74.8
10	5—Contact Mill	69.3
11	7—Impact Mill	66.6
12	5—Impact Mill	65.5
13	2A—Tube and Ball Mill	61.5
14	6—Impact Mill	58.0
15	4—Contact Mill	55.2
16	3—Impact Mill	52.5
17	4—Impact Mill	47.0
18	Not considered	....

By examination of the photomicrographs it is found that this classification does not indicate the degree of fineness below 200 mesh by a wide margin, for sample No. 1, tube and ball mill, in eighth place, appears to be much better than sample No. 1, impact mill, in the first place, and sample No. 4, contact mill, in the fifteenth place, appears to be just as good.

Nor by examination of these photomicrographs can any one type of pulverizer be shown to be better than any other, although the performance of individual machines can be compared to some extent, provided there is not too much difference in the way in which different coals break down during the process of pulverization. This point, together with considerations with regard to moisture content at the time of pulverizing, was not taken into account in the foregoing, and the appearance of the photographs submitted

need not, for these reasons, be taken as a final proof of the merits of the machines which made the samples.

Suggested Method of Estimating Fines

It is entirely probable that if the percentages of a sample were determined by passing it through a number of screens and a curve plotted using this information, the characteristics of this curve might give some indication of the fines distribution below 200 mesh, which is about as fine as it is practicable to go by sieving. This phase of the subject was not studied in connection with the data herein presented, but the method is advocated by one manufacturer of high-grade screening equipment.

Method of Sampling

The method of sampling determines to quite an extent the accuracy of the samples collected. This is especially true of the unit type of machines. In a test on one unit pulverizer, a variation of 8 per cent in the 200-mesh material was experienced with a corresponding variation of over 5 per cent in the 100-mesh material; this variation being found in taking samples across the discharge pipe. The finest material was at the surface and the coarsest at the center of the discharge passage. This condition has been observed by other investigators, and the use of a sampling pipe extending entirely across the discharge passage has been recommended.

The material used for precipitating or collecting the dust will also play a big part in the number of fines collected. The best material for filtering seems to be finely woven cloth, although a filter made of fine steel wool is being used with very good results.

Conclusions

However, this study does show conclusively that the standard 100-mesh and 200-mesh percentage method of testing pulverized coal is at fault, in that it is not complete enough to show the actual pulverizing work done and that it may actually be misleading in a comparison of two samples. The microscope should be consulted, or a more elaborate screen test run, in all cases where it is desired to know exactly what quality of pulverized coal is being delivered by the machine.

Aluminum and Its Light Alloys

Data on the Mechanical Properties of Alloys for Sand, Permanent-Mold, and Die Castings, Wrought Aluminum, High-Strength Alloys and Forgings Therefrom, Etc.

By ROBERT L. STREETER[1] and P. V. FARAGHER,[2] PITTSBURGH, PA.

ALUMINUM has advanced from the position of a laboratory curiosity to that of an important commercial metal in a comparatively short period of time. The properties of the metal upon which this development is based are primarily its lightness or low specific gravity, high thermal and electrical conductivity, pleasing appearance, resistance to atmospheric corrosion and to certain types of chemical attack, the non-toxicity of its compounds, and the ease with which it can be wrought. The commercially pure metal is quite soft in the cast or annealed condition and has only moderate strength when wrought cold.

The desire to improve the mechanical properties of the metal and at the same time retain its desirable properties has resulted in the development of a large number of light aluminum alloys. The increase in strength and hardness which is obtained in the alloys is gained at a sacrifice of some of the ductility and workability of the metal. In most cases the resistance to corrosion is lessened, although some of the alloys are at least the equal of the commercial grades of pure metal in this respect. Most of the alloys contain 90 per cent or more of aluminum; the specific gravities vary from 2.65 to 2.90 as compared with 2.70 for the commercially pure metal.

It is the purpose of this paper to make available to the engineer data on the mechanical properties of aluminum and its light alloys. The recent literature contains a large amount of information on the developments in this field. The data which have been published are, however, to a great extent the results obtained in laboratory investigations and do not represent minimum values which may be used by the designer for commercial materials. The data presented in this paper are minimum properties obtained from numerous tests of commercial material and may be used by the engineer with the assurance that such materials are available on the market.

Fig. 1 Aluminum Pipes 31 in. in Diameter Used for Transmission of Gases in a Nitric Acid Works

The term "aluminum," as commonly used, denotes not only the commercially pure metal but also the alloys in which aluminum is the principal constituent. Aluminum is available in a great variety of forms. It can be rolled, forged, extruded, drawn, spun, and cast. The list of commercial wrought forms includes plate, sheet, foil, tubing, bar, rod, wire, moldings, structural shapes, rivets, forgings, automatic-screw-machine products, and castings produced in sand, in permanent molds, and by the die-casting process.

Aluminum Casting Alloys

Although the mechanical properties and casting characteristics of commercially pure aluminum are not such as to recommend it for general casting purposes, it is used to some extent where its chemical and electrical properties are preferable to those of the common casting alloys.

It is possible by the addition of relatively small amounts of other elements to commercially pure aluminum to produce alloys which possess very satisfactory mechanical properties and good foundry characteristics, and at the same time retain in a large measure the desirable properties of the commercially pure metal. The most commonly used alloying elements or "hardeners" are copper, silicon, zinc, and manganese, and to a lesser degree, nickel and magnesium. These hardeners differ among themselves in the percentages which are required to produce a given increase in the tensile strength or hardness and also in the effects on the other properties which accompany the change in strength of the alloy. These facts are best seen by reference to Table 1, which gives the mechanical properties and approximate compositions of the most commonly used casting alloys of aluminum.

Of the large number of alloys which have been proposed, only a few have come into general use. The standardization on a relatively small number of alloys is the natural result of several factors. The necessity of simplifying the problem of the utilization of secondary metal, the desire to avoid complex alloys with their attendant difficulties of composition control, and the dictates of economy in the choice of alloying elements exercise the greatest influence in limiting the number of alloys.

The largest tonnage of castings produced from aluminum alloys is poured in sand molds. The most commonly used alloys are marketed in ingot form for remelting. They are manufactured in large lots under careful chemical and pyrometric control, and by their use the foundry may avoid the difficulties which are encountered in the preparation of alloys on a small scale.

The field for each of the methods of casting is rather sharply defined. The sand-casting process is applicable to the most varied types of work both as to size and shapes which can be produced. The accuracy of dimensions is not so great as in the permanent-mold or the die-casting processes, and in general more allowance must be made for machining and finishing operations. The surface finish is inferior to that obtained in metal molds.

Permanent-mold castings are used where a superior product is required but where a forging cannot be used, either because of the form of the part or because of cost considerations. The strength of a casting produced from a given alloy in a permanent mold is about twenty per cent greater than that obtained from a sand casting, and the hardness and ductility are correspondingly greater. The dimensions may be controlled more accurately than in a sand casting, and either a machined or polished surface will show greater freedom from defects. By the use of permanent-mold castings it is often possible to effect appreciable saving in weight due to the ability to design to closer limits. Because of the cost of producing the molds, this type of casting is available only for quantity production.

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The die-casting process is adapted to the production of castings in which extreme accuracy, uniformity, and superior finish are essential. In this process very thin walls may be cast, with the consequent saving of weight in the finished part. Holes may be cast to very close tolerances and the dimensions can be controlled so closely as to reduce machining operations to a minimum. Because of the excellent surface, polishing and finishing operations are greatly simplified. In this case also the die cost is such that the die-casting

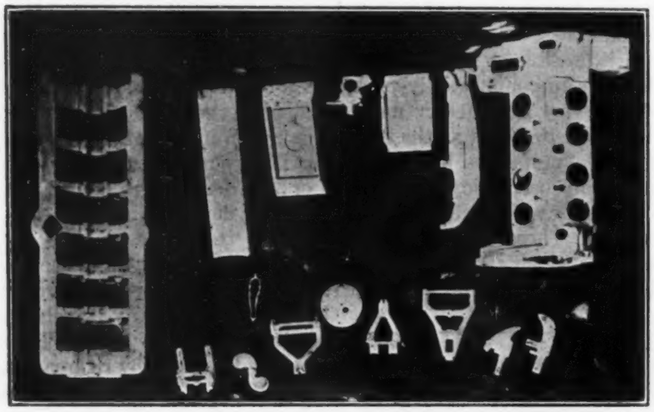


Fig. 2 Miscellaneous Assortment of Sand Castings

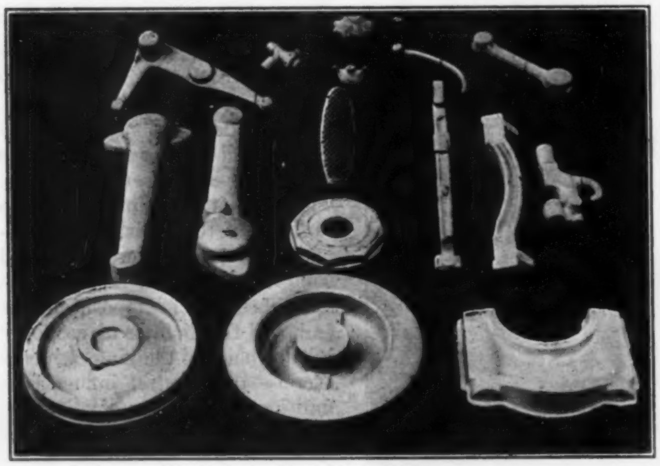


Fig. 3 Forgings and Permanent-Mold Castings

process is suitable only for castings which are produced in large quantities.

In comparing the accuracy with which these products can be produced the following comparison is of interest. For die castings tolerances are discussed in thousandths of an inch, for permanent-mold castings, in thirty-seconds and sixty-fourths, while for sand castings tolerances are considered in eighths and sixteenths.

TABLE 1 ALUMINUM CASTING ALLOYS

(Properties obtained from unmachined sand-cast test specimens)

Alloy No.	Approx. composition	Ultimate tensile strength, lb. per sq. in.	Elongation per cent in 2 in.	Approximate yield point, lb. per sq. in.	Brinell hardness number
100	99% aluminum..	12,000–14,000	15–25	4,000	25
12 (S.A.E. No. 30)	8% copper......	18,000–23,000	1–3	10,000	65
112 (S.A.E. No. 33)	7.5 copper, 1.5 zinc, 1.2 iron	19,000–24,000	1–2.5	11,000	65
109	12% copper.....	19,000–26,000	0–1.5	15,000	70
43 (S.A.E. No. 35)	5% silicon......	17,000–21,000	3–7	7,000	40
45	10% silicon.....	19,000–23,000	1–3	9,000	50
47[1]	13% silicon..... (Modified)	25,000–30,000	5–10	11,000	60
106	2% manganese..	16,000–20,000	3.5–6.5	6,000	40
195[1]	4% copper...... (Heat treated)	28,000–35,000	5.5–11	18,000	70
196[1]	5% copper...... (Heat treated)	36,000–45,000	0–2.5	27,000	115
145[1]	10% zinc, 2.5% copper, 1.2% iron	25,500–34,000	3–6	12,000	65

[1] The modification process by means of which the properties specified for No. 47 alloy are realized, the production of castings 195 and 196 in the heat-treated state, and alloy No. 145 are covered by patents or patent applications owned by the Aluminum Company of America.

Sand Castings

Table 1 lists the alloys which are most commonly used for the production of sand castings in the foundries of the Aluminum Company of America, together with the approximate chemical compositions and the mechanical properties which are obtained. The test specimens are poured in sand molds without chills or other means of artificial cooling and are tested without machining.

The values representing the lower limits of the ranges for tensile strength and elongation are regularly guaranteed; the average values are, in general, midway between the upper and the lower limits. The results which are obtained from test specimens machined from castings vary considerably with the nature of the casting and with the size and shape of the section from which the sample is taken. Sand castings which show 80 per cent of the tensile strength of the unmachined cast test specimen are considered indicative of very good foundry practice.

While it is true that more accurate measurements can be obtained from test specimens which are cast oversize and machined accurately to dimensions, the difference between the results which are obtained

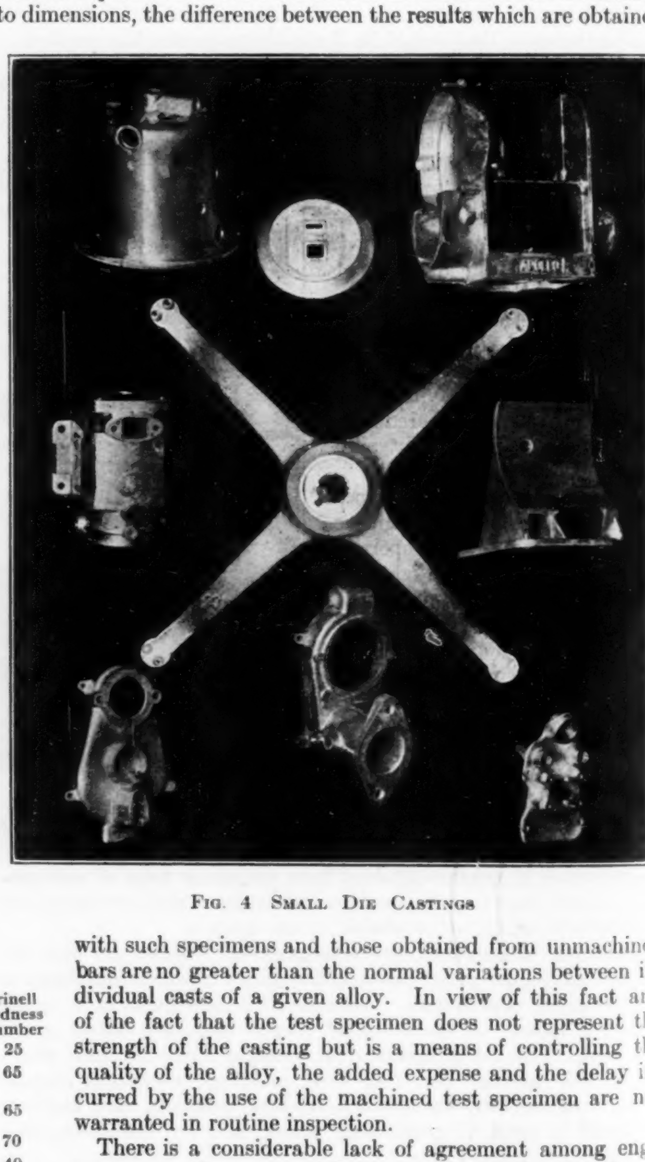


Fig. 4 Small Die Castings

with such specimens and those obtained from unmachined bars are no greater than the normal variations between individual casts of a given alloy. In view of this fact and of the fact that the test specimen does not represent the strength of the casting but is a means of controlling the quality of the alloy, the added expense and the delay incurred by the use of the machined test specimen are not warranted in routine inspection.

There is a considerable lack of agreement among engineers as to the proper definition of the yield point of nonferrous metals and also as to the best means of measuring it. The values given in Table 1 for the yield point consider this property to be the stress under which the elongation in the gage length of the test specimen is equal to one-half of one per cent of its initial length. This property is not regularly measured in routine inspection and the values given in the table are to be considered as approximate, and not as guaranteed minimum values. The measurement of Brinell hardness is subject to considerable vari-

ation, and the values for this property are also approximate average values.

Each of these alloys has its advantages and its disadvantages, and there is a field in which each excels. The commercially pure metal has the lowest strength and yield point and in addition is difficult to handle in the foundry, but its use is imperative in certain chemical and electrical equipment because of its characteristic properties. Alloys Nos. 12 and 112 are the most widely used of all the alloys and their tonnage is far in excess of all the others for general casting purposes. They are easily handled in the foundry and their extensive use in the automotive industry is proof of their satisfactory properties. No. 112 machines somewhat better than No. 12 and is stronger, but has slightly less ductility. For parts which must be leakproof under pressure, alloy No. 109 may be used, although this advantage is gained at a sacrifice of the toughness and resistance to shock which are shown by the alloys containing the lower percentage of copper.

The aluminum-silicon alloys are quite fluid at temperatures almost down to the freezing point, and they have a low solidification shrinkage. This combination of properties makes it possible to cast intricate shapes having both heavy and thin sections without the excessive use of chills and risers. The castings are dense and leakproof. Silicon has a lower specific gravity than aluminum and its alloys with aluminum are therefore somewhat lighter than commercial aluminum itself. This factor is significant in aircraft-engine construction where even small differences in weight are important. These alloys are perhaps the most resistant of all the casting alloys to salt-water corrosion, which fact makes them especially suited to marine construction. In remelting, somewhat greater care must be used since they show a greater tendency to

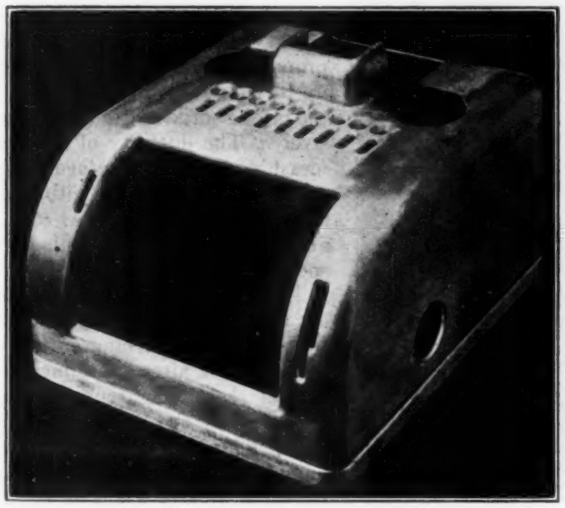


Fig. 5 Die-Cast Adding-Machine Frame, Weight 3.38 Lb.

absorb iron, which element has a harmful effect on the mechanical properties. It will also be noted that the yield points are lower in proportion to the ultimate tensile strength than in the other alloys, but their elongations are higher. These alloys are more difficult to machine than the other casting alloys.

The properties which are given for No. 47 alloy are obtained only by special modification treatments of the molten alloy according to processes which are covered by patents. Castings made from the unmodified alloy show coarse crystalline fractures and inferior mechanical properties, while castings from the modified alloy show extremely fine silky fractures.

Alloy No. 106 is used almost exclusively for small parts such as pipe fittings where the shrinkage can be easily taken care of. Such fittings are used extensively with wrought aluminum-manganese alloy (3S) pipe and tubing in order to reduce the tendency toward electrolytic corrosion. The alloy is quite resistant to salt-water corrosion.

The properties of Nos. 195 and 196 alloys are developed only after proper heat treatment according to processes covered by patents and patent applications. These alloys show remarkably high strengths and yield points, and the elongation is also very high in No. 195 alloy. These alloys age spontaneously on standing; in this process the strength and particularly the yield point increase and the elongation decreases somewhat. These alloys will naturally be chosen where the mechanical property requirements are sufficient to warrant the added expense of heat treatment.

Castings from No. 145 alloy have good strength and ductility, and are quite resistant to shock. While its properties are not equal to those of the heat-treated alloys, the fact that it does not require heat treatment will frequently cause it to be chosen for those purposes where the properties are adequate. This alloy is also subject to spontaneous aging and shows an increase in strength with some loss of ductility on standing. In common with other aluminum alloys containing relatively high percentages of zinc,

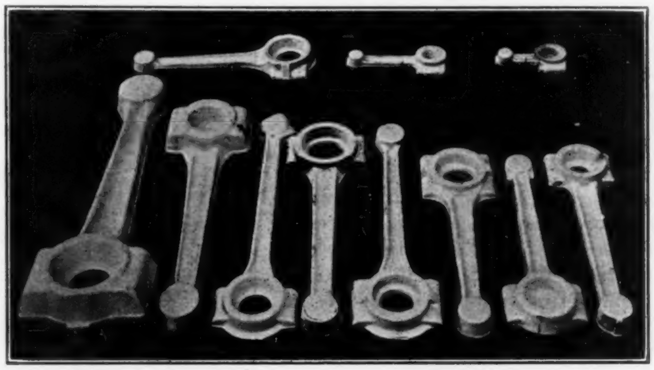


Fig. 6 Forged Connecting Rods

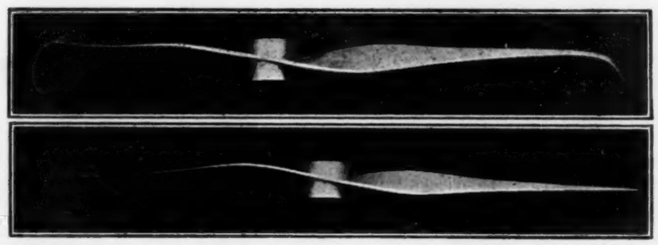


Fig. 7 Aluminum-Alloy Airplane Propeller Damaged by Impact on Water (above) and after Repairs Were Made (below)

it is not adapted for use at high temperatures since it loses its strength rather rapidly at elevated temperatures.

Permanent-Mold Castings

Some of the alloys which were considered with the sand castings are also used in the permanent-mold process, and in addition there are certain alloys which are intended primarily for use in this process. The art of producing permanent-mold castings is still new and is developing rapidly. Whereas most of the production in the past has been confined to castings in which the average weight would not exceed 3 lb., at the present time several castings are being run on a commercial scale in which the weight varies from 5 lb. to 13 lb. Such heavier castings must of necessity not present too great complexity in design.

In addition to the superior mechanical properties possessed by permanent-mold castings, the alloys have greater resistance to corrosion, and greater susceptibility to heat treatment where these processes are applicable, due to the fine grain and greater density of the metal.

Table 2 lists the more commonly used alloys and the mechanical properties which are obtained when they are cast in permanent molds in the form of the standard half-inch test specimens. In giving values for Brinell hardness it is necessary to point out that this measurement is subject to considerable variation, and the range is of necessity rather wide. The values for tensile strengths represent the ranges which are usually obtained in commercial production; the average value is somewhat higher than the mean of the minimum and maximum strengths which are given. In some cases small test specimens have been machined from castings to determine the variations in strength which may occur in different

sections. This specimen has a parallel section of 0.210 in. in diameter and 0.800 in. in length. The results indicate that in actual castings the strength may fall below the minimum values which are given in Table 2.

Die Castings

The die-casting process was originally developed for use with tin- and lead-base alloys; later zinc-base alloys were added, and finally the art developed to the point where aluminum alloys could be used. All of these alloys are used today, the alloy chosen for a given casting depending upon the requirements which must be met. Where the properties of lightness, corrosion resistance, pleasing appearance, and higher mechanical properties are desired, one of the aluminum alloys will be chosen.

The Aluminum Die Casting Corporation, located at Garwood, New Jersey, uses three different aluminum alloys under the trade name of "Alumac." The approximate composition and the mechanical properties of these alloys are given in Table 3. The properties are those which are obtained from die-cast test specimens having dimensions which simulate those of actual die castings. Because of the nature of the die-casting process, materially different results would be obtained from a die-cast bar of the form and dimensions of the standard test bar which is used for sand castings. The mechanical properties and the quality of the castings obtained with the aluminum-silicon and the aluminum-silicon-copper alloys are superior to those obtained with the aluminum-copper alloys.

The choice of the alloy to be used depends upon both the nature of the casting and the properties that are required. Because of the individual casting characteristics, the three alloys given in Table 3 cannot be used indiscriminately for the production of all types of die castings.

While light-weight castings are the rule, it is not uncommon to produce complicated die castings weighing as much as 10 lb. Some interesting examples of this class of work are shown in Figs. 4 and 5.

Wrought Aluminum

The wrought forms of aluminum are produced from commercially pure aluminum, from an alloy containing approximately one and one-fourth per cent of manganese, and from the recently developed alloys which are susceptible of heat treatment. Some little material is produced from other alloys for special purposes, but the amount is limited and is not to be considered as commercial production.

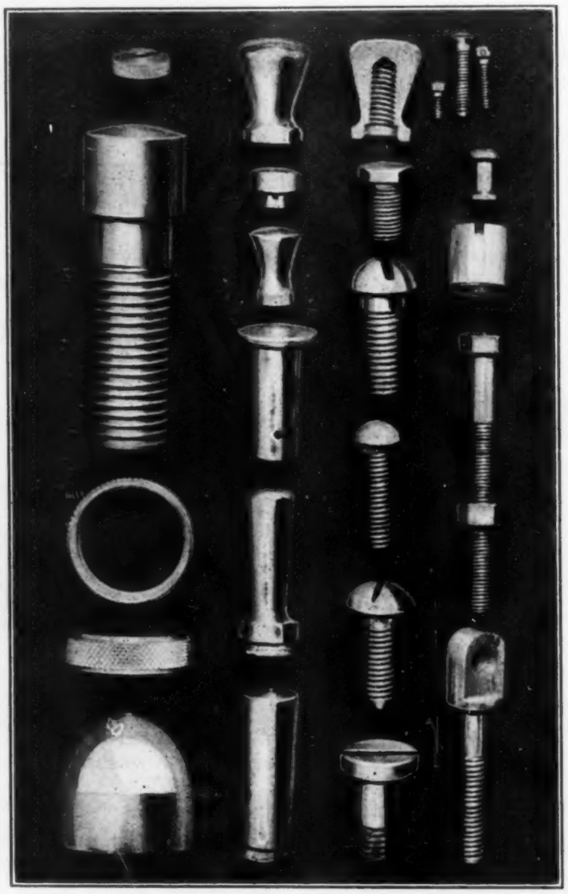


Fig. 8 Assorted Screw-Machine Products

TABLE 3 MECHANICAL PROPERTIES OF DIE-CAST ALLOYS

(Obtained from round, die-cast test specimen, 0.252 in. in diameter.)

Alloy No.	Approximate composition, per cent		Tensile strength, lb. per sq. in.	Elongation, per cent in 2 in.	Brinell hardness number
83	Copper Silicon	2 3	25,000–28,000	3–6	55–65
85	Copper Silicon	4 5	28,000–30,000	2.5–4	60–70
13	Silicon	13	28,000–30,000	1–3	70–80

TABLE 2 PHYSICAL PROPERTIES OF PERMANENT-MOLD-CAST ALLOYS

(Standard 0.505-in. test specimen, cast in permanent mold.)

Alloy No.	Approximate composition, per cent		Tensile strength, lb. per sq. in. Min.	Max.	Elongation, per cent in 2 in. Min.	Max.	Brinell hardness number
43	Silicon	5.0	18,500	24,500	3.0	8.0	40–45
108	Copper Silicon	4.5 5.5	21,000	29,500	1.0	4.5	65–80
45	Silicon	10.0	24,500	29,500	4.5	10.0	45–56
112	Same as sand-cast 112 (as cast)		21,000	29,000	1.5	3.0	70–90
122	Copper Iron Magnesium	10.0 1.2 0.25	22,000	30,000	.0	1.5	85–105
125	Silicon Iron Tin	5.0 1.0 2.0	17,500	22,500	4.3	8.0	40–45
151	Copper Iron Tin	5.5 1.0 1.0	20,500	26,500	3.5	7.5	60–70
152	Copper	10.0	20,500	29,500	1.0	3.0	85–110
195	Copper	5.5	22,000	28,000	3.0	6.0	60–70
	Heat-Treated Alloys						
	Heat-treat number						
195	4		35,000	39,000	5.0	9.0	70–90
195	10		48,000	54,500	1.0	1.5	110–140
122	2		24,000	30,000	0.5	1.5	90–120
122	7		40,000	48,000	0.5	1.0	125–160
122	12		24,500	32,500	0.5	1.0	125–160
122	14		24,000	30,500	0.5	2.0	95–125
122	15		26,000	32,500	0.5	1.5	115–125

2S and 3S

The commercially pure aluminum which is supplied to the trade in the various wrought forms is usually required to show a minimum aluminum content of 99 per cent. This metal is designated as "2S" by the Aluminum Company of America, and this designation is used extensively in the trade. The manganese alloy, designated as "3S," is appreciably stronger than 2S and yet is quite workable in the softer tempers.

In the fully annealed state these metals are quite soft and ductile. When worked cold they are strain-hardened, the tensile strength, yield point, and hardness increasing in proportion to the amount of reduction up to a certain limit, beyond which the rate of hardening increases progressively. The ductility of the metal as measured by the percentage elongation decreases very rapidly with the first amounts of reduction by cold work and at a gradually diminishing rate for successive reductions.

The tempers of 2S and 3S products are based on the properties produced by the strain hardening of the metal by cold work after annealing. In the case of sheet, the tempers may be indicated by the amount of this decrease in thickness measured in gage numbers (the American Wire Gage or Brown & Sharpe Gage is commonly used), since the width remains practically unchanged as the sheet passes through the rolls. For tubing, bar, etc. the actual reduction in cross-sectional area must be calculated to correspond to the reduction which is produced in sheet.

Sheet, tubing, and bar are regularly produced from both 2S and 3S in the annealed temper, in the hard temper, and in three intermediate tempers, designated one-quarter hard, half hard, and three-quarters hard. Sheet in the hard temper is produced by reducing the thickness by cold rolling twelve or more gage numbers after annealing; the same temper is obtained in bar and tubing by a corresponding reduction in cross-sectional area by cold work. While a reduction corresponding to twelve gage numbers in sheet is the minimum for the hard temper, many products have appreciably greater reductions than this as produced according to present commercial practice. This is particularly true of thin sheet, which may be rolled from the annealed slab to the finish gage without intermediate annealing.

The minimum tensile strengths of the intermediate tempers are calculated, however, on the basis of the range between the minimum values for the annealed temper and for the hard temper, regardless of the fact that in certain classes of commercial material the actual difference may be greater. For example, the half-hard

temper has a minimum tensile strength approximately half-way between that of the minimum values for the annealed and for the hard tempers. Similar relations hold for the quarter-hard and three-quarters-hard tempers.

It will be seen from the tables of properties that there is some overlapping of the ranges for the various tempers in both 2S and 3S. This is due to several causes. The slight differences in the composition of different lots of metal, variations in annealing conditions, and the tolerances which are required in fabricating to any given dimensions are all factors in commercial operating practice which influence the final properties of the material.

The elongation is a property which is influenced very largely by the size and shape of the test specimen. This influence is so great that in the case of thin sheet the elongation is of little value in indicating the differences in the workability of the different tempers. The effect of the size of the specimen can be eliminated in the case of bar or other sections from which a round specimen can be machined, by measuring the elongation over a gage length proportional to the diameter of the specimen.

In Tables 4 and 5 are given the approximate ranges for the tensile strengths of the different tempers of 2S and for 3S, together with the minimum or specification values for the elongation of sheet. The elongation of bar and tubing is in most cases appreciably higher than that of sheet because of the effect of the shape of the test piece on the test results. The actual data for these products are not included in the tables but can be obtained from the manufacturer, for the specific sizes and tempers for which the data may be desired.

TABLE 4 PROPERTIES OF 2S ALUMINUM (99 PER CENT MINIMUM ALUMINUM)

	Tensile strength,	Elongation for sheet (minimum), per cent in 2 in. B & S Gage						
Temper	lb. per sq. in.	2–4	5–6	7–9	10–16	17–20	21–24	25–28
Soft	12000–15000	30	30	30	30	25	20	15
1/4 Hard	14000–18000		10	10	9	7	6	..
1/2 Hard	16000–20000			7	7	5	4	3
3/4 Hard	19000–23000				4	3	2	1
Hard	22000–35000				4	3	2	1

TABLE 5 PROPERTIES OF 3S ALUMINUM (1.25 PER CENT MANGANESE-ALLOY SHEET)

	Tensile strength,	Elongation for sheet (minimum), per cent in 2 in. B & S gage						
Temper	lb. per sq. in.	2–4	5–6	7–9	10–16	17–20	21–24	25–28
Soft	16,000–20,000	25	25	25	20	20	15	10
1/4 Hard	19,000–23,000		8	8	7	6	5	..
1/2 Hard	21,000–26,000			6	6	4	3	2
3/4 Hard	25,000–28,000				4	3	2	1
Hard	27,000–45,000				4	3	2	1

Strong Alloys

The development of the high-strength aluminum alloys has made aluminum with its properties of lightness, corrosion resistance, and pleasing appearance available as a structural material. Alloys of this type are in commercial production and are available in a large variety of forms: sheet, tubing, bar, rod, wire, forgings, rivets, automatic-screw-machine products, angles and channels both rolled and extruded, and other extruded structural shapes. These alloys are produced in several tempers, the properties varying over a fairly wide range. In the case of these materials the temper depends upon the condition as regards heat treatment.

The Aluminum Company of America produces three alloys of this class: 17S, an alloy of the duralumin type, containing copper, magnesium, and manganese; 25S, containing copper, manganese, and added silicon; and 51S, containing magnesium and added silicon. Each of these alloys has its specific heat-treatment process and its characteristic properties. It should be noted that while these alloys in the cast condition show some improvement on heat treatment, the cast structure must be thoroughly obliterated by working if they are to develop maximum properties in the heat-treatment operation.

These alloys all possess the property of strain hardening when they are worked cold. This strain hardening is removed and the alloy rendered workable by annealing at a suitable temperature. This temperature must be carefully controlled since too low a temperature will fail to soften the metal and too high a temperature will produce effects analogous to those which result from heat treatment though lesser in degree.

The heat treatment consists in heating the alloys to a suitabl temperature and quenching; the actual temperature varies somewhat for the different alloys. Immediately after quenching the alloys are much stronger than in the annealed state, but are distinctly more workable than when in the fully aged condition.

From this point the characteristics of the metals diverge appreciably. The alloy 17S on standing at room temperature undergoes a spontaneous aging, during which process the strength and hardness increase very markedly and the elongation also shows a slight increase. This change proceeds quite rapidly at first then more slowly, and is practically completed in about four days. If it is desired to take advantage of the greater ease of working of the unaged material, the forming must be completed within one or two hours of the time of quenching.

The alloy 51S also undergoes spontaneous aging at ordinary temperatures, but the change is much less pronounced than in the case of 17S. If this alloy is to develop its maximum properties, it must be aged at elevated temperatures. Under these conditions there is a very marked increase in the tensile strength, yield point, and hardness, and an appreciable decrease in the elongation.

The alloy 25S, even on standing for a long time at ordinary temperatures, shows only an insignificant change in properties. If, however, it be heated to a suitable aging temperature, changes in properties occur which are comparable with those which take place spontaneously in 17S.

The effects of the heat-treatment operations may be removed by subsequently heating to the annealing temperature and cooling.

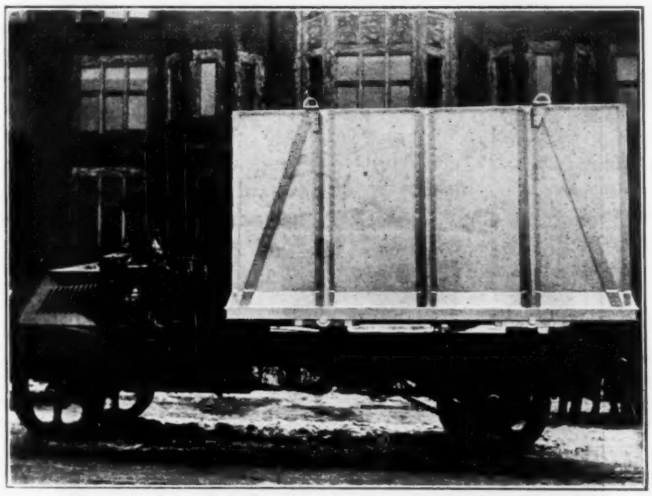


Fig. 9 Removable Truck Body and Shipping Container

There appears to be some difference in the properties of this annealed material and that which has not been previously heat-treated in the case of 25S.

The various tempers of these alloys are designated in accordance with the following system: The symbol which designates the temper is added to the symbol for the alloy, the letter O indicates the annealed or soft temper, the letter T the quenched and aged or fully heat-treated temper, and the letter W (used only with 25S and 51S) material which has been quenched but not artificially aged; e.g., 25SO, 17ST, 51SW, etc.

The mechanical properties of 17S and 25S are very similar in corresponding tempers, although there are characteristic differences in their behavior in various forming operations and under different conditions of service. It is interesting to note that the properties in the heat-treated temper are comparable with those of mild steel. The public is familiar with the use of these metals in aircraft construction; the framework of the *Shenandoah* is made of 17S supplied by the Aluminum Company of America, and that of the *Los Angeles*, from duralumin of German manufacture. These metals are also being used in automobile and particularly in autobus construction, as well as in certain parts of railway cars, street cars, and ships. A recent development is in the construction of unit containers for less-than-car-load-lot freight shipments. The advantages of a metal having the strength of mild steel with a weight approximately two-fifths as great do not need to be enumerated.

The alloy 51S in the heat-treated temper has a tensile strength about 10,000 lb. per sq. in. less than that of 17S or of 25S, but

the yield point and hardness are practically identical with those of the stronger alloys. This alloy can be worked with great ease in the softer tempers and the finished articles can be heat-treated to develop maximum properties. Although the elongation of 51S is lower than that of 25S or 17S in the heat-treated temper, in those cases where the material is not subjected to severe forming operations, the high yield point and hardness make this material attractive.

As was stated previously, the properties which are developed in these alloys in the heat-treatment operations depend upon the amount of work which is done upon the cast ingot in reducing it to the desired size. The properties which are given in Tables 6 to 8 will be met by material which in commercial production has received sufficient work to permit the development of maximum properties. According to present commercial practice this will include sheet up to $^1/_8$ in. in thickness, bar and rod up to $^3/_4$ in. in diameter, tubing in all commercial sizes, all moldings, and smaller shapes. In heavier material the tensile strength and yield point may fall below the values given by as much as 5000 lb. per sq. in. The elongation for this heavier material may also fall below the values given by as much as 4 per cent.

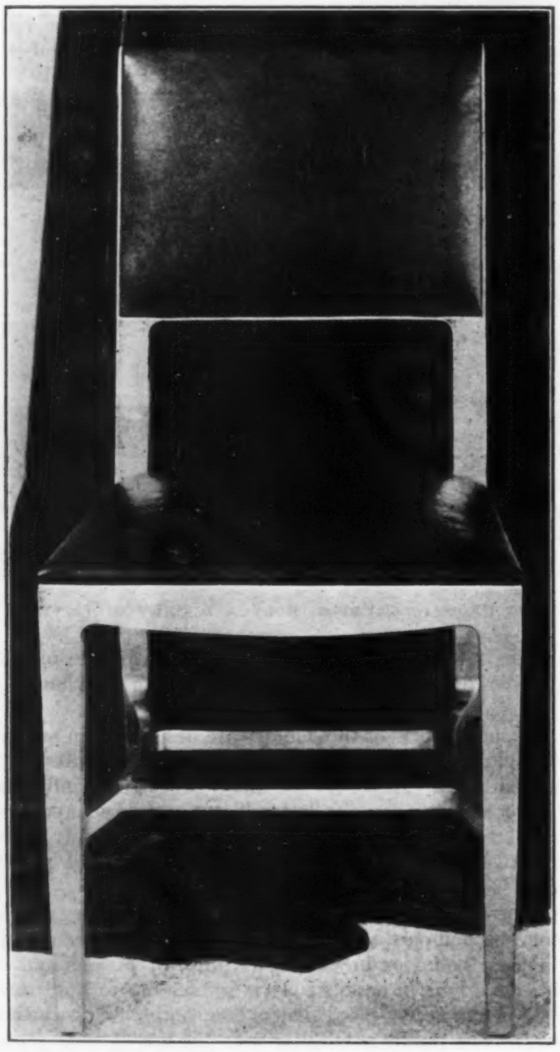


FIG. 10 ALUMINUM STRAIGHT-BACK CHAIR

As was stated when discussing the properties of 2S and 3S products, the measurement of elongation is very much dependent upon the shape of the test specimen. The minimum values for this property are those which are obtained from sheet of intermediate thickness and for bar and rod up to $1^1/_2$ in. in diameter or distance across flats.

In the case of the annealed tempers the material is guaranteed not to exceed the maximum values for tensile strength which are given; the minimum value is not guaranteed.

Shapes which have been produced from these alloys by extrusion and have not been heat-treated subsequently, possess properties intermediate between those of the annealed and the "as quenched" tempers. The metal is extruded at an elevated temperature and the issuing material is cooled in air. This is equivalent to a mild heat treatment, although the temperature of extrusion is not the optimum for heat treatment nor is it subject to close control.

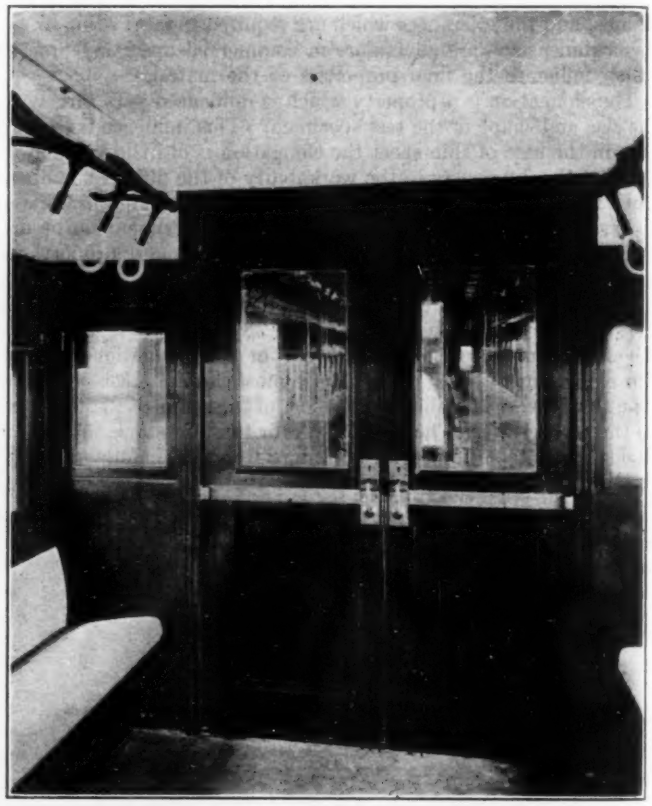


FIG. 11 INTERIOR OF RAILWAY PASSENGER COACH SHOWING DOORS AND INTERIOR CONSTRUCTION OF ALUMINUM

There is considerable variation in this material as extruded, but for certain purposes the properties are adequate.

The alloys Nos. 25S and 51S are covered by patents owned by the Aluminum Company of America.

TABLE 6 MECHANICAL PROPERTIES OF 17S ALUMINUM ALLOY

	17SO	17ST
Tensile strength, lb. per sq. in.	25,000–35,000	55,000–63,000
Yield point, lb. per sq. in.	7,000–10,000	30,000–40,000
Elongation, per cent in 2 in.	12–23	18–25
Brinell hardness (500 kg., 10-mm. ball)	42–50	90–110

TABLE 7 MECHANICAL PROPERTIES OF 25S ALUMINUM ALLOY

	25SO	25SW	25ST
Tensile strength, lb. per sq. in.	25,000–35,000	45,000–53,000	55,000–63,000
Yield point lb. per sq. in.	7,000–10,000	18,000–25,000	30,000–40,000
Elongation, per cent in 2 in.	12–23	15–20	18–25
Brinell hardness (500 kg., 10-mm. ball)	45–50	70–85	90–110

TABLE 8 PROPERTIES OF 51S ALUMINUM ALLOY

	51SO	51SW	51ST
Tensile strength, lb. per sq. in.	14,000–18,000	30,000–40,000	45,000–50,000
Yield point, lb. per sq. in.	4,000–6,000	15,000–20,000	30,000–40,000
Elongation, per cent in 2 in.	15–30	20–30	10–18
Brinell hardness (500 kg., 10-mm. ball)	25–32	55–70	85–100

FORGINGS

The Aluminum Company of America produces strong-alloy forgings in three different grades, these are in accordance with the values shown in Table 9, which represent guaranteed minimum properties.

TABLE 9 PROPERTIES OF STRONG-ALLOY FORGINGS

	Grade 1	Grade 2	Grade 3
Tensile strength, lb. per. sq. in.	55,000	50,000	40,000
Elongation, per cent in 2 in.	16	15	12
Brinell hardness (500 kg. load, 10-mm. ball)	100	90	90

The grade which is supplied depends upon the duty which is to be performed by the forging. Material having properties listed under grade 1 in Table 9 is usually supplied for connecting rods for automobiles, sewing-machine arms, gear blanks, and propellers for aircraft. The high strength combined with lightness make strong aluminum-alloy forgings ideal for high-speed reciprocating parts: vibration and inertia stresses are reduced, with the consequent increase in the life of the machine. The advantages of direct babbitting are also gained by the use of these forgings. Gears made from these alloys can be machined more accurately and more rapidly than is possible with cast iron or steel, and their operation at high speeds is much quieter. The propellers for aircraft forged from these alloys are of about the same weight as wood propellers and have the advantage of longer life. Experience has shown that the metal propellers are not injured by hail or rain, and that in many cases it has been possible to repair damage which was caused by a faulty landing.

For miscellaneous hardware the properties given for grades 2 or 3 in Table 9 are more commonly specified. For this use strong aluminum alloys possess the advantage of ease of finishing and polishing. The finish is permanent, since there is no plated coating to rub off in use. In addition to permanence of finish there is the further advantage of lower cost in comparison with nickel-plated brass.

Automatic-Screw-Machine Products

The Aluminum Screw Machine Products Company manufactures a complete line of automatic-screw-machine products from strong aluminum alloy which it distributes through the Aluminum Company of America. These products have the physical properties which are given in Table 6 for 17ST. They possess the advantages of ease of finishing and permanence of finish which was mentioned under forgings. The cost as compared with nickel-plated brass is very much in favor of the aluminum-alloy products. In many cases aluminum-alloy products are chosen in preference to brass on the basis of cost alone, even where the brass is not to be nickel-plated.

General

Several reproductions of photographs are included in this paper to show some of the applications which are being made of this very interesting metal. No attempt will be made to list the uses which are being made of aluminum and its alloys. It is interesting to note the fact that many parts can be produced from aluminum and its alloys more cheaply than they can from other metals the price of which per pound is considerably lower. The greater speed of machining and finishing aluminum combined with the fact that the weight of the part from aluminum is approximately one-third that of the same part from brass or iron, are the factors which make this result possible. In other cases the decrease in weight of the entire assembly with the consequent longer life and the saving of power during its operation, are the principal considerations in favor of the use of aluminum.

Aluminum alloys offer very attractive possibilities for decorative castings and objects of art. Statues have been cast from aluminum with very pleasing results. One of the best-known manufacturers of lighting fixtures is producing some very beautiful effects in cast aluminum alloys colored by means of certain processes which are applicable to this metal, and in satin finishes produced either by sand blasting or by dipping. Office furniture has been made from aluminum alloys; some examples are shown in the accompanying illustrations. The cap of the Washington Monument and the finial of the Standard Oil Building in New York City are aluminum-alloy castings.

In contemplating the future of aluminum in the engineering field, one is impressed with the necessity of further and continued research among the strong alloys. Wherever a reduction in weight will result in a saving of power, aluminum or other light alloys will have to be considered in design; and just as sure as the physical properties and cost of manufacture of those alloys become more satisfactory, so will they receive more favorable consideration by engineers.

Test of a Uniflow Engine

Results Obtained with Loads Ranging from One-Quarter to Full Load (400 kw.), with Two Different Steam Pressures, Two Different Back Pressures, Two Different Percentages of Clearance, And with Saturated and Superheated Steam

By GEO. H. BARRUS,[1] BOSTON, MASS.

THIS paper consists of a brief account of a series of tests which the author has recently conducted on a four-cylinder vertical uniflow engine, non-condensing, driving a 400-kw. a.c. Burke generator, direct connected, as shown in Fig. 1, with loads ranging from one-quarter to full load, with two different steam pressures, two different back pressures, two different percentages of clearance, and with saturated and superheated steam.

The tests were conducted for the Great Western Laundry Company, of Chicago, making use of the testing plant of the Ames Iron Works, Oswego, N. Y., in which the engine was designed and built.

The cylinders and heads are steam-jacketed. The cylinder jackets extend around a belt at both top and bottom of the cylinders with openings leading to the jacket spaces in each head. The steam on its way to the steam chest passes through the jackets, and the condensate, if any, is free to drop into the bottom heads, whence it is discharged through a mechanical trap. Except at very small loads the sweep of the steam keeps the condensate in motion, and the trap rarely discharges either water or steam.

The admission valves are double-beat poppets, lifted vertically by a horizontal camshaft. This shaft is moved laterally by a horizontal centrifugal spring-resisted governor, which varies the cut-off according to the lateral position of the cams.

The cylinders are arranged in two pairs, with cranks 90 deg. apart. The two corresponding cranks of either pair are 180 deg. apart. Two cylinderfuls of steam are thus withdrawn from the source of supply at each quarter of a revolution. The total volume of these piston displacements is 0.71 cu. ft., that of the entire jacket spaces and steam chests is 8.2 cu. ft., and that of the throttle valve and piping from the cylinder flange to the stop valve on the steam drum, 2.0 cu. ft. These volumes are purposely mentioned to permit the comparison of the amount of steam withdrawn from the storage spaces at each double steam admission with the total space. The amount withdrawn each time is thus only about one-twelfth of the jacket volume. In this connection it was noticeable that the fluctuations of steam pressure at the throttle valve were extremely small; indeed, the cock on the steam gage at the throttle was kept wide open, and the gage pointer vibrated not more than its own width. The steam-pipe diagrams taken at the throttle valve revealed the same substantial absence of fluctuations, being practically straight lines. These results are obviously brought about by the influence of the multiple cylinders and the storage spaces of the jackets. The practical absence of pressure variation in the steam main contributes not only to steam economy but to structural advantages as well, for it makes the pipe itself secure with a minimum amount of anchorage; further, it enables the size of the pipe to be reduced to the smallest permissible diameter—in this case 5-in. extra heavy. The velocity of the steam in the pipe at the greatest load (15,214 lb. per hr., average) is estimated at 108 ft. per sec. (6480 ft. per min.).

The moving parts of the engine are shut in by a casing, and no adjustment from the outside can be made, while in operation, except to vary the speed by tightening or loosening the governor spring. This construction admits of the efficient use of a pressure oiling system for the lubrication of the entire engine, no oil cups or grease cups being required.

The engine as equipped for testing purposes is shown in Fig. 1. Its dimensions are given in Table 1. The apparatus for measuring the steam consumption consists of a surface condenser of ample capacity, placed below the level of the engine and discharging by gravity into a pair of steel-plate weighing tanks, which are alternately filled and emptied.

In conducting the tests the methods recommended by the A.S.M.E. were substantially followed. The tests were carried out in a continuous series for each set of conditions, starting with the light load, then changing to the next load, and so on, or vice versa. Each test was of sufficient duration to collect a half-dozen or more tankfuls at a substantially constant rate, the intervals between different loads being long enough to fully establish the changed conditions. Under each load the current from the generator was absorbed by a water rheostat, and the load was maintained constantly at the desired point by hand regulation at the switchboard or rheostat terminals. The loads selected (exclusive of direct-current exciter, using from 3 to 5 kw.) were 100, 200, 300, and 400 kw.

Fig. 1 Uniflow Engine for 400-kw. a.c. Generator Equipped for Testing Purposes

TABLE 1 DIMENSIONS OF UNIFLOW ENGINE TESTED

1	Number of cylinders	4
2	Diameter of each cylinder	14 in.
3	Diameter of each piston rod	$2^3/_8$ in.
4	Stroke of each piston	16 in.
5	Normal speed	300 r.p.m.
6	Piston speed in feet per minute at 300 r.p.m.	800 ft.
7	Clearance volume in per cent of piston displacement as calculated from drawing, first and second series	22 per cent
8	Clearance volume calculated for third and fourth series	17 per cent
9	Inside diameter of steam pipe	4.8 in.
10	Inside diameter of each of the two exhaust pipes	8 in.

There were four series of tests, each with the four loads specified, namely:

1 Saturated steam, 125 lb. pressure, atmospheric exhaust
2 Saturated steam, 125 lb. pressure, 5 lb. back pressure
3 Saturated steam, 150 lb. pressure, atmospheric exhaust
4 Superheated steam, 150 lb. pressure, atmospheric exhaust.

The leading data and results are presented in Tables 2, 3, 4, and 5.

The steam on all the saturated-steam tests was practically dry steam, a throttling calorimeter, showing almost constantly a temperature of 277 deg. fahr. with 125 lb. pressure at the throttle valve, indicating a moisture content of less than one-half of one per cent. No correction was made for this small amount of moisture.

The superheating boiler of the plant was not in service while the saturated-steam tests were being conducted.

[1] Cons. Steam Engr. Mem. A.S.M.E.

For presentation at the Spring Meeting, Milwaukee, Wis., May 18 to 21, 1925, of The American Society of Mechanical Engineers. All papers are subject to revision.

The indicated horsepower was determined by taking diagrams and kilowatt readings simultaneously, and correcting for any departure from the even 100-, 200-, 300-, and 400-kw. loads, which were the points at which the averages were continuously maintained. The diagrams were taken from three-way cocks according to the usual test-block method. The horsepowers should be slightly reduced owing to the error of the three-way cocks. This error, however, is practically offset by a corresponding error due to the

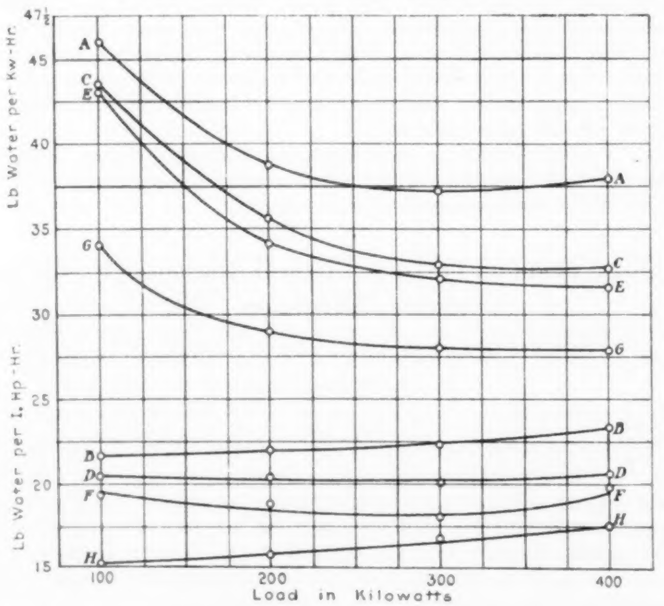


FIG. 2 CURVES SHOWING PERFORMANCES OF THE UNIFLOW ENGINE

Curves A and B: Saturated steam, 125 lb. pressure, 5 lb. back pressure.
Curves C and D: Saturated steam, 125 lb. pressure, atmospheric exhaust.
Curves E and F: Saturated steam, 150 lb. pressure, atmospheric exhaust.
Curves G and H: Superheated steam, 150 lb. pressure, atmospheric exhaust.

TABLE 2 TESTS OF UNIFLOW ENGINE—FIRST SERIES

(Saturated steam, 125 lb. pressure, atmospheric exhaust, 22 per cent clearance)

	Proportionate Load			
	1/4 load	1/2 load	3/4 load	Full load
1 Gage at throttle valve, lb.	125	125	126	125.5
2 Electric load (exclusive of exciter), kw.	100	200	300	400
3 Water per hour, lb.	4360	7144	9908	13,124
4 Indicated horsepower	211.6	350.8	491.8	635.2
5 Water per i.hp-hr., lb.	20.6	20.4	20.1	20.7
6 Water per kw-hr. (exclusive of exciter), lb.	43.6	35.7	33.0	32.8

TABLE 3 TESTS OF UNIFLOW ENGINE—SECOND SERIES

(Saturated steam, 125 lb. pressure, 5 lb. back pressure, 22 per cent clearance)

	Proportionate Load			
	1/4 load	1/2 load	3/4 load	Full load
1 Gage at throttle valve, lb.	125.3	129	124	124.4
2 Electric load (exclusive of exciter), kw.	100	200	300	400
3 Water per hour, lb.	4655	7776	11,203	15,214
4 Indicated horsepower	215.5	352.7	499.4	652.6
5 Water per i.hp-hr., lb.	21.6	22.0	22.4	23.3
6 Water per kw-hr. (exclusive of exciter), lb.	46.1	38.9	37.3	38

TABLE 4 TESTS OF UNIFLOW ENGINE—THIRD SERIES

(Saturated steam, 150 lb. pressure, atmospheric exhaust, 17 per cent clearance)

	Proportionate Load			
	1/4 load	1/2 load	3/4 load	Full load
1 Gage at throttle valve, lb.	151	153.2	152.4	150.8
2 Electric load (exclusive of exciter), kw.	100	200	300	400
3 Water per hour, lb.	4314	6834	9668	12,652
4 Indicated horsepower	222.4	361.9	533	634.5
5 Water per i.hp-hr., lb.	19.4	18.9	18.1	19.9
6 Water per kw-hr. (exclusive of exciter), lb.	43.1	34.2	32.2	31.6

TABLE 5 TESTS OF UNIFLOW ENGINE—FOURTH SERIES

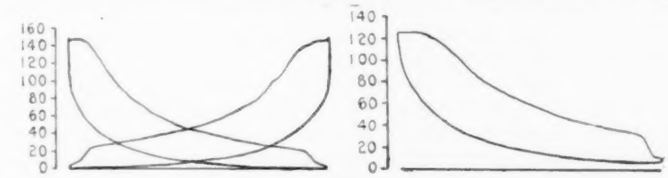
(Superheated steam, 150 lb. pressure, atmospheric exhaust, 17 per cent clearance)

	Proportionate Load			
	1/4 load	1/2 load	3/4 load	Full load
1 Gage at throttle valve, lb.	153	152	152.2	151.4
2 Temperature by throttle thermometer, deg. fahr.	469	443	427	437
3 Superheating at throttle thermometer, deg. fahr.	109	83	67	77
4 Electric load (exclusive of exciter), kw.	100	200	300	400
5 Water per hour, lb.	3411	5807	8430	11,148
6 Indicated horsepower	223.2	365.2	501.5	633.3
7 Water per i. hp-hr., lb.	15.3	15.9	16.8	17.6
8 Water per kw-hr. (exclusive of exciter), lb.	34.1	29.0	28.1	27.9

reducing motion in use which acts the opposite way, and these errors may be disregarded.

The economy results of the various tests are shown graphically by points on Fig. 2, in which horizontal distances represent the load in kilowatts and vertical distances pounds of steam consumed per i.hp-hr. and per kw-hr. In each case a curve is drawn showing what may be considered the average curve of performance. It is interesting to note the effect which superheating produced on the curve H of that series as compared with the corresponding curve F given with saturated steam. In the superheated-steam case the curve is substantially a straight line.

The manner in which the steam is distributed in the cylinders by the use of the uniflow principle and its attending valve mechanism and arrangement of cylinders may be seen by reference to the two sample indicator diagrams reproduced in Figs. 3 and 4. Fig.



FIGS. 3 AND 4 SAMPLE INDICATOR DIAGRAMS FROM UNIFLOW ENGINE

Fig. 3: Throttle gage, 153 lb.; back pressure, 0 lb.; m.e.p., 45.1 lb.
Fig. 4: Throttle gage, 125 lb.; back pressure, 6.7 lb.; m.e.p., 42.9 lb.

3 shows the performance with atmospheric exhaust, and Fig. 4 with a back pressure of $6^1/_2$ lb.

In connection with the operation of the uniflow principle in this engine, the question of cylinder condensation comes to the front. Table 6 is added with a view of showing the steam accounted for by the indicator diagrams in one of the series of tests with saturated steam, as well as the proportion this bears to the actual steam consumption. The high percentages in the last line of the last two columns (87 and 88 per cent) reveal excellent conditions regarding condensation and leakage.

TABLE 6 STEAM ACCOUNTED FOR BY DIAGRAM IN FIRST SERIES OF TESTS

	Load in Kilowatts			
	100	200	300	400
1 Apparent cut-off, per cent	4.1	8.0	11.2	16.9
2 Steam accounted for by diagrams per i.hp-hr., lb.	13.72	16.96	17.49	18.2
3 Actual steam consumed per i.hp-hr., lb.	20.6	20.4	20.1	20.7
4 Percentage accounted for	66.6	83.1	87.0	88.0

At the close of the second series of tests the admission valves were tested for leakage under a standing pressure, with engine blocked, the steam which leaked being revealed by escape into the air through the indicator piping. There was practically no leakage. When the throttle valve was shut and the steam was retained in the steam chests, the pressure within dropped at the extremely low rate of 5 lb. per min., requiring ten minutes' time to be reduced from 120 lb. to 70 lb

Synopses of Other Spring Meeting Papers

The Parallel Operation of Hydro and Steam Plants

Some Operating and Economic Features That Should Receive Careful Attention

By F. A. ALLNER

Gen. Supt., Pennsylvania Water and Power Company, Baltimore, Md., Mem. A.S.M.E.

DUE to the low generating costs of modern steam plants the margin of saving offered by a hydro development is frequently quite small. The utmost utilization of combined hydro-steam-source power, however, has become of greater economic importance in recent years. The economic service of hydro power is usually expressed as replacement value of the equivalent amount of steam power. This comprises two different elements: one, the steam investment cost for the hydro demand service; the other, the steam generating cost for the hydro energy delivered to the load system.

A hydro-steam development that is not equipped with seasonal storage can render the greatest demand service to a given system load if, on the days of greatest steam demand on the system coinciding with minimum flow, the hydro plant supplies the peaks and the steam plant the base of the system load. The greatest energy contribution from the hydro plant is obtained by letting it carry the base portion of the system load during high flow and having the peak portion produced by steam.

General and specific methods are explained by which these economic principles are put into practice. Particulars are given of a system of load signaling by means of small changes in frequency above or below normal which has been found very useful for a more perfect distribution of load during certain hours when it is otherwise difficult to secure the desired division of generation.

Hydro-steam parallel operation may produce a favorable operating combination as these two sources of power can supplement each other to mutual advantage in a number of desirable service features. Inherent limitations which serve to prevent too short a governor traversing time on hydro units are explained, as well as oscillograms of "load on" and "load off" tests recording speed, gate travel, and pressure in wheel pit.

Particulars are given of a proposed ideal hydro-steam parallel operation where the steam station will be located immediately adjacent to the hydro plant. The generating units of both plants will be operated from the same control board. Circulating water for the condensers will be drawn from and returned to the forebay of the hydro plant. During frazil-ice attacks this arrangement is expected to minimize capacity reductions at the hydro plant. There is a natural seasonal diversity in the time of overhauling work at the two types of plants. It will be possible to keep the same skilled labor force employed more steadily throughout the year and to use the same shop facilities for the repair work of both plants.

THE papers, abstracted on this and the following pages are being printed in full in pamphlet form for the Spring Meeting. Copies of them may be secured by filling out the blank on page 447 of this section of the May issue of MECHANICAL ENGINEERING and mailing it to the office of the Society.

The remainder of the papers preprinted for the meeting will be found in this special Section Two of MECHANICAL ENGINEERING.

The tentative program for the Spring Meeting appears on pages 391 and 392 of this section.

Steel-Foundry Management

By R. A. BULL

Dir., Electric Steel Founders' Research Group, Chicago, Ill.

THE author discusses those steel-foundry problems that in his opinion have the greatest general significance in this highly specialized branch of manufacture. He presents a brief analysis of the industry, explaining its technical and commercial divisions and the significance of each from the standpoint of output, for the purpose of more clearly indicating the nature of the industry under consideration.

Many occupations in the steel foundry are listed in order to explain the complex nature of the operations for which a manager is responsible. The branches of a company organization are assigned to staff and line departments. Reasons are given for certain classifications, regarding which procedures occasionally vary. Policies governing staff departments are discussed separately, not for the purpose of enumerating all duties ordinarily performed, but with the intention of provoking discussion regarding certain factors considered by the author to be of fundamental importance, about which there are differences of opinion.

The subject of compensation both for workmen and for foremen is emphasized because the author believes this is a detail of management which is of very great significance.

Duty Tests of Vertical Triple-Expansion Pumping Engines, Milwaukee, Wis.

Results Obtained At Riverside Pumping Station

By CHARLES A. CAHILL

Consulting Engineer, Cahill & Douglas, Milwaukee, Wis. Mem. A.S.M.E.

MILWAUKEE, Wisconsin, has equipped its new Riverside Pumping Station with three vertical triple-expansion pumping engines. The reason for this choice of engines of this type was their great reliability, high economy, and low cost of maintenance. The author believes that the units A and B recently tested have shown a duty record that has not been equaled to date by any using steam as a working medium for pumping water.

The Rational Design of Covering for Pipes Carrying Steam up to 800 Deg. Fahr.

By W. A. CARTER and E. T. COPE

Respectively, Engineer, Research Dept., The Detroit Edison Co., Mem. A.S.M.E., and Research Dept., The Detroit Edison Co., Detroit, Mich.

THE authors present an analysis of the problem of determining the most economical thickness of pipe covering for steam pipes carrying steam superheated to temperatures of 500 deg. fahr. and above, based on the work of Heilman, Eberle, and others. Two cases are considered, one in which a single insulating material is used, while in the second it is considered necessary to use a material of higher heat-resisting properties between the pipe and the covering used in the first case. Curves showing the net monetary saving for various thicknesses of covering for a 6-in. pipe are included. Equations for the calculations involved are included and the procedure of making the calculations explained. Three appendices deal with some of the assumptions made in the analysis.

Boiler Furnaces for Pulverized Coal

By A. G. CHRISTIE

Professor of Mechanical Rngineering, Johns Hopkins University, Baltimore, Md. Mem. A.S.M.E.

POWDERED coal is used more widely every year for furnaces under boilers. An analysis of the fundamentals of the combustion of the coal and of the effect of radiant heat and flame on the performance of such furnaces is presented in this paper. Certain features secondary to the furnace and dealing with preparing and drying coal and handling ash are also discussed briefly.

This analysis indicates that the following conditions are de-

sirable for the highest efficiency and maximum capacity of a given furnace: Coal should be finely ground, thoroughly dry, and preheated before entering the furnace. Primary and secondary air should be highly preheated. Turbulence should exist inside the furnace. The walls should be water-cooled. New methods of handling ash and preventing the discharge of dust into the air should be developed. These will lead toward greater capacity for a given furnace volume and to high boiler efficiencies.

Lake Waters for Condensers

By A. G. Christie

Professor of Mechanical Engineering, Johns Hopkins University, Baltimore, Md. Mem. A.S.M.E.

This paper points out the persistence of stratification of warm- and cold-water layers in our northern lakes and other deep waters. The cold bottom layers make excellent cooling-water supplies for condensers and would permit operation at high vacuum throughout the whole year. The savings from increased vacuum are such that engineers should give this factor careful consideration, both in the selection of plant site and in the design of intakes, particularly for large power stations. Temperature-depth studies of the particular lake should be made to furnish exact data upon which a rational decision can be based.

A Review of Steam-Turbine Development

By Hans Dahlstrand

M.E., Steam Turbine Engrg. Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis. Mem. A.S.M.E.

This paper is chiefly concerned with the effects which the use of steam at higher pressures and temperatures has had upon the efficiencies of steam turbines and upon the materials used in the construction of their parts. The use of high-back-pressure steam turbines, to be installed in connection with boilers of higher pressure in such a way as to exhaust into the steam mains and turbines of existing plants, is carefully analyzed for units of 10,000- and 30,000-kw. capacity, and the effects on the efficiency are graphically presented. A discussion of materials for use with the higher pressures and temperatures is included, with some curves showing the results of investigations made by the Allis-Chalmers Company on various metals and the characteristics which should be possessed by a metal suitable for use at 1000 deg. fahr. The paper also contains some comments on corrosion and erosion of turbine blades, and shows the effects of these destructive forces on blades of different composition.

Mechanical Features Affecting the Reliable and Economical Operation of Hydroelectric Plants

Translated by L. C. Marburg, Mem. A.S.M.E.

By E. A. Dow

Mechanical Engineer, New England Power Construction Co., Worcester, Mass.

This paper deals with the subjects of flashboards, trashracks, rack rakes, sluice and headgates, penstock valves, air vents, and discharge-measuring devices from the standpoint of economy and reliability of operation based almost entirely on the New England Power Company's practice. It stresses the importance of reducing head losses and leakage and adhering to strength and simplicity in the design of hydraulic equipment.

Comparison of Actual Performance and Theoretical Possibilities of the Lakeside Station

By M. K. Drewry

Technical Engineer, Power Plants, Milwaukee Electric Railway & Light Co., Milwaukee, Wis. Jun. A.S.M.E.

To show the degree of perfection in the design and operation of a high-efficiency, straight Rankine-cycle station, pointing out the magnitude of each individual heat and availability loss occurring in actual practice, is the object of this paper. Operating and test figures of the Lakeside Station have been assembled and a comparison of theory and practice has been recorded.

Recent Investigations in Turning and Planing and a New Form of Cutting Tool

By Hans Klopstock

Pres., Klopstock Steel Co., Berlin, Germany

This paper gives an account of experiments conducted in the machine-tool laboratory of the Polytechnic Institute of Berlin. The cutting tests proper were preceded by a study of the lathe and the instruments used, to ascertain their behavior under various conditions. In the main tests it was aimed to determine the influence upon the cutting forces of the following factors: Cutting speed, chip section, shape of tool, and characteristics of the materials cut.

As a result of these observations a new form of tool has been designed which, the author claims, permits a higher cutting speed and a larger chip section than is practicable with the standard tools now used. The results of some of the tests made in various German railway shops are given, in which the relative life of the cutting edges of the new and the old tools under exactly the same conditions was compared.

It is claimed, from results obtained in various foreign shops, that on the average production can be increased about 30 per cent by means of the new tool.

Torsional Vibrations and Critical Speeds of Shafts

By Arnold Lack and Charles B. Jahnke

Respectively, Engineer and Chief Engineer, Fairbanks, Morse & Co., Beloit, Wis.

This paper is an analysis of torsional vibrations and critical speeds of shafts. These magnitudes, as shown in the paper, can be calculated for any engine when all necessary data are given. The various characteristics of torsional vibrations are measured with a special instrument called the "Torsiograph," which shows by means of "torsiograms" the degree of irregularity of rotation of the shaft.

The stresses in the shaft due to its vibrations are also computed, and means of avoiding dangerous vibrations are shown. Results of a number of tests are given, which were carried out on: (*a*) an apparatus for demonstration of torsional vibrations; (*b*) an experimental horizontal oil engine; (*c*) a vertical two-cylinder Diesel engine driving two generators; (*d*) and a vertical four-cylinder marine engine.

Stress Concentration Produced By Holes and Fillets

By S. Timoshenko and W. Dietz

Research Laboratory, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa. Respectively, Mem. A.S.M.E. and Non-Member.

In many practical cases a very high stress concentration is produced by holes, grooves, notches, and sharp variation of cross-sections. This stress concentration is particularly undesirable where materials undergo reversal of stress. Coefficients of safety as hitherto employed have been large enough to cover such weakness. The modern tendency in design is to increase working stresses, thereby obtaining lighter and more economical structures, and concentration of stress is accordingly receiving more attention than formerly.

The authors attack a number of practical problems relating to holes and fillets, and employ several methods of approach: namely, analytical method giving approximate solutions for certain simple cases; photoelastic method, by means of which stress concentration can be studied if the problem is a two-dimensional one; Lueders' line method, or the study of certain lines appearing on the polished surfaces of a mild-steel specimen subjected to simple tension or compression, at the points of highest stress concentration; and fine extensometer measurements at points of stress concentration. Analytical and experimental methods are found by the authors to be in satisfactory agreement as far as static loads are concerned. When reversal of stress is involved, the weakening effect of stress concentration can only be established accurately on the basis of fatigue tests.

The Activated-Sludge Sewage-Disposal Plant at Milwaukee

Its General Operation and the Fundamental Principles Involved

By JOHN ARTHUR WILSON

Consulting Chemist, Sewerage Commission of Milwaukee.

THE problem confronting the Milwaukee Sewage Commission at the beginning of its work in 1913 was to separate the city's sewage—now having a flow of 85,000,000 gal. daily—into an effluent pure enough to discharge safely into Lake Michigan, its source of drinking water, and dry solid matter in a form permitting its economical shipment and use as a fertilizer. The activated-sludge process was adopted, which took care of the effluent part of the problem, and after prolonged and intensive engineering and chemical research a method was devised for reducing the sludge to an attractive dry powder with a high fertilizer value. The paper discusses in detail the methods used in removing both coarse and finely divided materials from the sewage, the mechanism of aeration, various phases of the sludge problem, relative filtering efficiency, effect of adding acid and aluminum sulphate, dewatering the sludge, preparation of the dry material as fertilizer, etc.

Radiation in the Pulverized-Fuel Furnace

By WALTER J. WOHLENBERG and DONALD G. MORROW

Respectively Associate-Professor of Mechanical Engineering, Yale University. Assoc-Mem. A.S.M.E., and Student at Yale University, New Haven, Conn.

THIS paper deals with the fundamentals concerning radiation in the pulverized-fuel furnace. It is shown that the radiating power through the flame surface depends primarily on the size of the particle and that, based on the flame-surface area, its magnitude relative to black radiation is low. The heat-absorption intensity at the cold surface, however, may be considerably higher than the relative radiance of the flame. This factor depends on both the amount and the disposition of the refractory furnace lining. Application of the method outlined enables, by an analytical process, quantitative evaluation of the furnace energy process, and the data yielded are of such a nature as to indicate by comparison which furnace proportions will give the best results.

A Code of Design for Mechanical Springs

By JOSEPH K. WOOD

Consulting Engineer, New York, N. Y. Mem. A.S.M.E.

THIS paper first gives an entirely new derivation of the general spring formulas developed by the author from the numerously scattered orthodox spring formulas and presented in his paper on Mechanical Springs at the A.S.M.E. Annual Meeting in December, 1924. The two sets of formulas, although derived independently, are identical in fabrication of terms, and since the new derivation is based upon the direct application of the individual terms, this agreement establishes the general formulas on a more logical and practical basis. There are slight differences, however, in the specific values of the stress-method and form-of-section constants, which in the case of springs of the uniform-flexure type account exactly for differences which have been found between calculated and actual test results. Complete research is urged to confirm this finding definitely, and until such work is done the author will employ the constants that agree with the orthodox formulas. In view of the remarkable manner in which the new derivation establishes the logical arrangement of the generalized formulas, the author has drawn up and included in the paper a brief code of design for mechanical springs, which he is led to believe will serve as a nucleus for a more complete and final code in the future.

Contributors to this Issue

L. V. Andrews

L. V. Andrews, author of the paper on A Microscopic Study of Pulverized Coal, was born in Stewardson, Ill. He attended high school in Decatur, Ill, and later studied courses given by the International Correspondence Schools and the Alexander Hamilton Institute. He has been connected with the Lyon Lumber Co., the Mississippi Valley Structural Steel Co., the McLaughlin Coal Reduction Co., all of Decatur, Ill., and the Riley Stoker Corporation, Worcester, Mass. He is at present employed with the latter company in its development department, where he has been working since 1918 with pulverized-coal equipment. During 1918 he was stationed at Carnegie Institute of Technology, Pittsburgh, with the 298th Aero Squadron.

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G. H. Barrus

G. H. Barrus, consulting engineer, of Boston, Mass., writes on Tests of a Uniflow Engine. Mr. Barrus was graduated from the Massachusetts Institute of Technology in 1874 with the degree of B.S. in mechanical engineering, and then served for six years as engineer for George B. Dixwell, who provided and donated to M.I.T. the first steam laboratory used in any technical school or college in the United States, and which was employed for the Dixwell investigations on superheated steam. From 1880 to the present time Mr. Barrus has been engaged in the consulting field in steam engineering, and has numbered among his clients many manufacturing establishments. In the course of his work he has conducted over a thousand boiler tests and has taken over 25,000 indicator diagrams.

Mr. Barrus has been very active in the work of The American Society of Mechanical Engineers, serving as a member of a number of important committees. He is the inventor of the Barrus steam calorimeter, a draft gage and a steam meter, as well as of drainage improvements for paper-machine driers. He was a Massachusetts member of the Board of Judges of the World's Columbian Exposition in 1893, and was a member of the National Advisory Board on Tests of Fuels and Structural Materials appointed by President Roosevelt.

W. L. DeBaufre

William L. De Baufre, who presents in this issue an Analysis of Power-Plant Performance Based on the Second Law of Thermodynamics, is chairman of the mechanical-engineering department of the University of Nebraska. He is also consulting engineer for the U. S. Bureau of Mines, being a member of the Board of Helium Engineers and of the Advisory Committee on the Use of Oxygen or Oxygenated Air in Metallurgical and Allied Processes. For a number of years he was mechanical engineer at the U. S. Naval Engineering Experiment Station, Annapolis, Md.

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H. S. Falk

Harold S. Falk, vice-president and works manager of the Falk Corporation, writes on A National Apprenticeship Program. Mr. Falk was born in Milwaukee, Wis., where he attended both grammar and high school. He then entered the University of Wisconsin, from which he was graduated in 1906. His summer vacations during the school period were spent working in various departments of the Falk Corporation, manufacturers of heavy-duty oil engines, gears, and steel castings. Upon being graduated he entered the employ of that concern as assistant to the superintendent. Sometime later he was appointed superintendent, then general superintendent of the plant, and in 1923, vice-president and works manager.

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P. V. Faragher

P. V. Faragher, co-author with R. L. Streeter of the paper on Aluminum and Its Light Alloys, received his A.B. from the University of Kansas in 1909 and then spent four years in graduate study at the University of Kansas, the University of California, and the research laboratory of physical chemistry of the Massachusetts Institute of Technology, receiving his Ph.D. from the latter in 1913. He then returned to the University of Kansas where he held the position of assistant professor, later becoming associate professor of chemistry. During 1918 he held a fellowship at the Mellon Institute of Industrial Research, where he studied the properties of magnesium and its alloys. In 1919 he entered the employ of the Aluminum Co. of America, where he first worked in the research bureau, later becoming connected with the company's technical direction bureau.

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G. E. Hagemann

G. E. Hagemann, co-author with J. A. Shepard of Formulas for Computing the Economies of Labor-Saving Equipment, was graduated from Rutgers University in 1912 with the degree of B.S. in mechanical engineering. He worked for a year with Frank B. Gilbreth in his management-installation work at the New England Butt Co., Providence, R. I., and then for a brief period was connected with the Worthington Pump & Machinery Corporation in centrifugal-pump and water-meter testing. For five years he served as an instructor in mechanical engineering at the University of Pennsylvania, and then became mechanical engineer for the Warren Foundry & Pipe Co. in Phillipsburg, N. J. Four and a half years later he accepted his present position of associate editor of *Management and Administration.*

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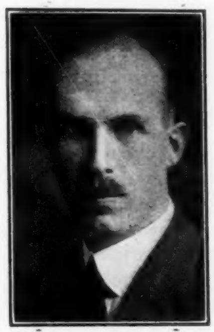

J. Fletcher Harper

J. Fletcher Harper, author of Defects in Large Forgings, attended the University of Wisconsin for three and one-half years, taking the course in electrical engineering, following which he served a special apprenticeship course at the Allis-Chalmers Manufacturing Co. He was connected with an electrical company in Milwaukee for one year, returning to the Allis-Chalmers Manufacturing Co. in July, 1916, to take charge of the heat-treating departments. In September, 1918 he was made assistant superintendent of the forge department in the same plant, and in April, 1921, was appointed research engineer of the manufacturing department of the company, which position he now holds.

GEORGE LANGFORD, JR.

George Langford, Jr., author of the paper on An Application of the Formulas for Computing Economies of Labor-Saving Equipment, was graduated from the engineering college of the University of Minnesota in 1924 with the degree of B.S. in mechanical engineering. Since then he has been connected with the Belden Manufacturing Co., of Chicago, Ill., in the capacity of assistant engineer.

* * * * *

E. H. LICHTENBERG

Erich H. Lichtenberg, author of Labor-Saving Equipment in Road Construction, is chief engineer of the Koehring Co., Milwaukee, Wis. He was educated in the University of Wisconsin extension school, the International Correspondence School, and the Alexander Hamilton Institute. He was for one year in the employ of the Louden Machine Co., Fairfield, Iowa, and from 1906 to 1907 served as patent-office draftsman in Springfield and Chicago, Ill. Later he designed and had charge of the building of ore-reduction machinery for the Kent Ore Reduction Co., of Chicago and Milwaukee, and of the designing of special machinery for the Whitman & Barnes Co., West Pullman, Ill. He has been associated with the Koehring Co. since 1911.

* * * * *

I. E. MOULTROP

I. E. Moultrop started his engineering career in 1882 by going with the Whittier Machinery Co. of Roxbury, Mass., as an apprentice in the machine shop. Following his apprentice term he went into the drafting room, and in due course was promoted to be head draftsman. He stayed with them until 1892 when he resigned to accept a position as engineer on mechanical construction work with the Boston Edison Company, and has been with that company ever since, advancing progressively to the position which he now holds, assistant superintendent of the construction bureau, which Bureau handles all the construction work done by the company.

Mr. Moultrop is at present a member of the A.S.M.E., A.I.E.E., Boston Society of Civil Engineers, N.E.L.A., and Association of Edison Electric Illuminating Companies. He is also a member of the Boiler Code Committee and Power Test Code Sub-Committee on Turbine Testing of the A.S.M.E.

Mr. Moultrop's prominence in the activities of the engineering work of the N.E.L.A. has been an outstanding feature of his career. He has served on its Prime Movers Committee, and the Steam Turbine and Gas Engineering Committee which proceeded the Prime Movers Committee, some ten or twelve years.

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EDWARD W. NORRIS

Edward W. Norris is a mechanical engineer, with Stone & Webster, Inc. He was graduated from the University of Pennsylvania in 1911 and joined the Society the following year. For five years he was in the engineering department of the Southwark Foundry and Machine Co., designing power-plant equipment and doing research work. He then spent a year with the Mead-Morrison Manufacturing Co. During the War he went to the Hog Island Shipyard where he supervised the installation of machinery and was later master mechanic at the structural fabricating shops. He went to Boston in 1919 with the C. B. Roberts Engineering Co., petroleum engineers, having charge of fuel oil installations. Three years later he entered the Engineering Division of Stone & Webster, Inc., taking the position he now holds.

* * * * *

J. A. SHEPARD

J. A. Shepard, co-author with G. E. Hagemann of Formulas for Computing the Economies of Labor-Saving Equipment, is vice-president and consulting engineer of the Shepard Electric Crane & Hoist Co. From 1880 to 1893 Mr. Shepard was one of three partners in the firm of W. H. Shepard & Sons, manufacturers of agricultural implements in Montour Falls, N. Y., where he served successively as molder, patternmaker, machinist, draftsman, salesman, and business manager. For the next nine years he was chief engineer of the W. H. Shepard & Sons' Bridge Co., in charge of the design and construction of plant and products. From 1902 to 1908 Mr. Shepard was chief engineer of the General Pneumatic Tool Co., the successor to the company with which he had just previously been connected. This concern in turn became the Shepard Electric Crane & Hoist Co., which Mr. Shepard served as vice-president and chief engineer before being appointed to his present position.

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Lewis K. Sillcox, general superintendent of motive power of the Chicago, Milwaukee & St. Paul Railway Co., writes on Factors Concerning the Economics of Shopping Steam Locomotives. Mr. Sillcox is a graduate of the Institute of Mechanical Engineers, Brussels, Belgium, receiving his M.E. in 1903. For three years immediately after he was connected with the New York Central Lines where he learned the machinist's trade and operating methods in the mechanical department. He was then for one year connected with the McSherry Manufacturing Co., Middletown, Ohio, as assistant general shop superintendent, resigning to become mechanical engineer in charge of the design of equipment and shops of the Illinois Traction System, Decatur, Ill. From 1910 to 1912 Mr. Sillcox was with the Canadian Car & Foundry Co., in Montreal, Canada, and for the next four years was associated with the Canadian Northern Railway System, Toronto, as mechanical engineer in charge of the design of locomotives, cars, shop tools, etc. In 1916 he accepted the position of mechanical engineer in charge of car work for the Illinois Central Railroad, Chicago, Ill., and shortly afterward became master car builder for the Chicago, Milwaukee & St. Paul Railway Co., of which concern he is now general superintendent of motive power.

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R. L. STREETER

R. L. Streeter and **P. V. Faragher** are co-authors of the paper on Aluminum and Its Light Alloys. Mr. Streeter is a 1903 graduate of the University of Pennsylvania. He engaged in practical engineering work until 1910, when he became connected with Rensselaer Polytechnic Institute as assistant professor of mechanical engineering. He served in the Army from May to October of 1919, and upon receiving his discharge became chief mechanical engineer of the Aluminum Co. of America. He is now vice-president of the United States Aluminum Co. in charge of the fabricating plants.

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R. J. Wadd, who writes on Economic Efficiency of the Full-Automatic Turret Lathe in Comparison with the Semi-Turret Lathe, has been since 1921 chief engineer of the Shepard Electric Crane & Hoist Co., Montour Falls, N. Y. He received his B.S. in mechanical engineering from Michigan Agricultural College and then entered the employ of the Shepard Electric Crane & Hoist Co., on engineering and sales work. During the war he was connected with the Chemical Warfare Service, returning to the Shepard Co. upon being discharged from the Army.

The following papers, to be presented at the Milwaukee Spring Meeting, will be available in pamphlet form and may be secured without cost by any member of the Society.

Check papers desired and mail to the Secretary.

Order Number		Reserved for Date Stamp
Written		
Date	By	

Spring Meeting Papers Available

Distribution of these papers by mail will commence about May 1

Check Here (X)	Authors and Papers	Date Shipped	By
	Allner, F. A., The Parallel Operation of Hydro and Steam Plants		
	Bull, R. A., Steel-Foundry Management		
	Cahill, Charles A., Duty Tests of Vertical Triple-Expansion Pumping Engines, Milwaukee, Wis.		
	Carter, W. A., and Cope, E. T., Rational Design of Covering for Pipes Carrying Steam up to 800 Deg. Fahr.		
	Christie, A. G., Boiler Furnaces for Pulverized Coal		
	Christie, A. G., Lake Waters for Condensers		
	Dahlstrand, Hans, A Review of Steam-Turbine Development		
	Dow, E. A., Mechanical Features Affecting the Reliable and Economical Operation of Hydroelectric Plants		
	Drewry, M. K., Comparison of Actual Performance and Theoretical Possibilities of the Lakeside Station		
	Klopstock, H., Recent Investigations in Turning and Planing, and a New Form of Cutting Tool		
	Lack, A., Torsional Vibrations and Critical Speeds of Shafts		
	Timoshenko, S., and Dietz, W., Stress Concentration Produced by Holes and Fillets		
	Wilson, John A., The Activated-Sludge Sewage-Disposal Plant at Milwaukee		
	Wohlenberg, Walter J., and Morrow, Donald G., Radiation in the Pulverized-Fuel Furnace		
	Wood, J. K., A Code of Design for Mechanical Springs		

To the Secretary, A.S.M.E., 29 West 39th Street, New York City.

Please send copies of the papers checked above to

Print Name..

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SPRING MEETING MAY 18-21, 1925

MILWAUKEE

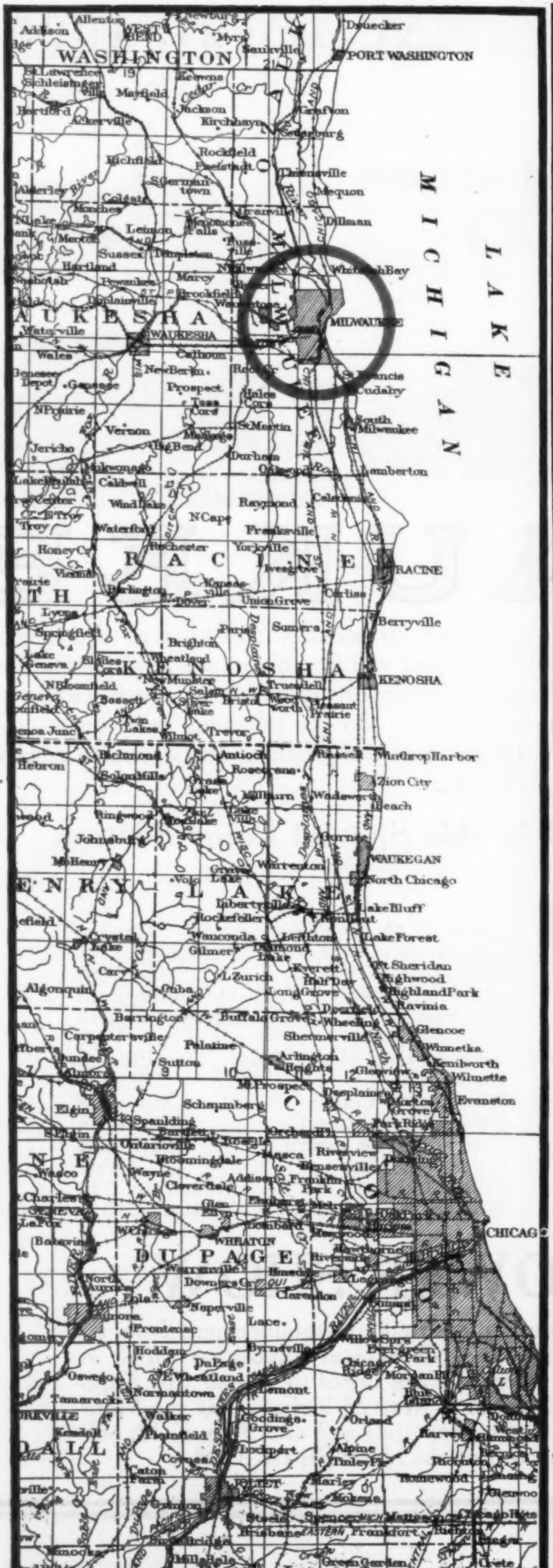
and while here, take advantage of the opportunity to meet in person the executives of concerns in whose products you are interested. In many cases you will be able to see new machines in operation, or to secure first-hand information about manufacturing processes which will be of direct benefit from a business or professional standpoint. On the following color pages, the concerns located here present special information regarding their products and extend a cordial invitation to visit their plants, (see map on pages 2 and 3).

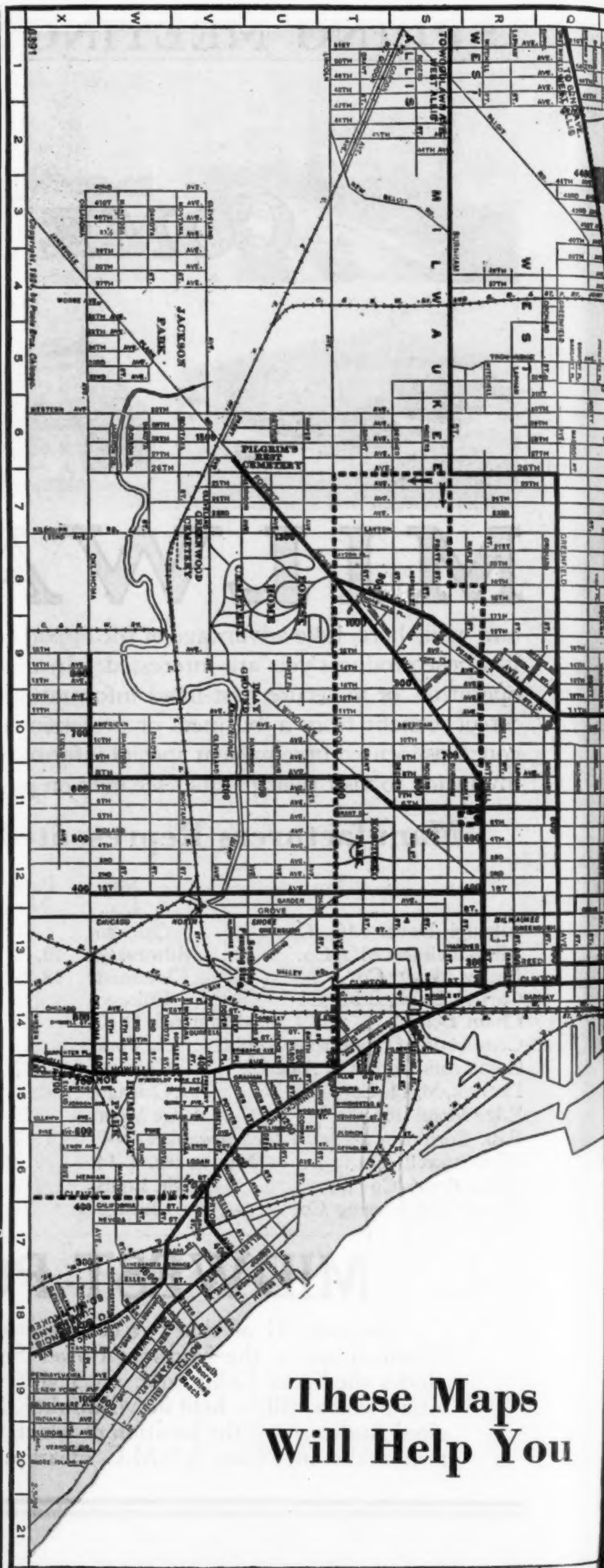
Manufacturers Represented in this Special Color Section

	Map Loc.	Page No.
Albaugh-Dover Mfg. Co	Chicago	30
Allis-Chalmers Mfg. Co	Milwaukee	10, 11
Bailey Meter Co	Cleveland	28, 29
Carrick Engineering Co	Chicago	15
Chain Belt Co	Milwaukee, O-10	13
Combustion Engineering Corp'n	New York	24
Conveyors Corp'n of Amer	Chicago	17
Detrick, M. H. Co	Chicago	20
Edge Moor Iron Co	Edge Moor	25
Falk Corp'n	Milwaukee, N-7	7
Filer-Stowell Co	Milwaukee, T-14	8
Heine Boiler Co	St. Louis	19
Illinois Engineering Co	Chicago	21
James, D. O. Mfg. Co	Chicago	6
Johnson Service Co	Milwaukee, L-15	12
Kellogg, M. W. Co	New York	23
Midwest Power Show (Inc.)	Milwaukee, K-12	31
Nordberg Mfg. Co	Milwaukee, X-14	9
Permutit Co	New York	27
Republic Flow Meters Co	Chicago	4, 5
Ric-wil Co	Chicago	14
Riley Stoker Corp'n	Worcester	22
Schutte & Koerting Co	Philadelphia	16
Techno Service Corp'n	New York	18
Union Iron Wks	Erie	26
Vilter Mfg. Co	Milwaukee, T-14	12
Wrought Washer Mfg. Co	Milwaukee, T-16	14

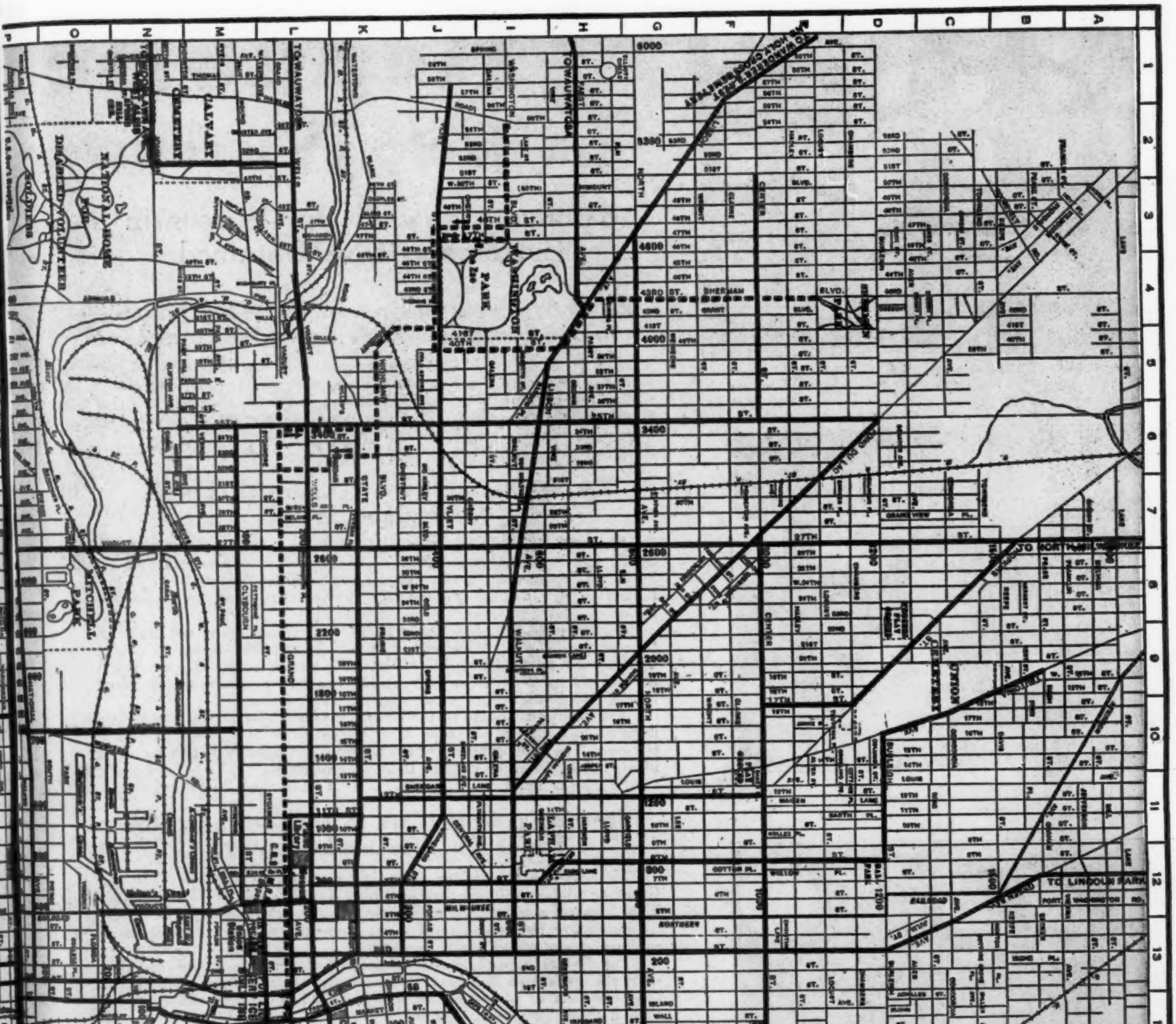
MIDWEST POWER SHOW

On page 31 of this two color section is presented an announcement from the Management of the Midwest Power Show and Mechanical Exposition which includes the list of Exhibitors. A.S.M.E. Members are urged to attend this Exposition which will be held in Milwaukee, May 18 to May 22 inclusive, at the Municipal Auditorium; the location of which on the map (pages 2 and 3) is K-12, only a short distance from A.S.M.E. Headquarters at the Hotel Pfister, L-14.

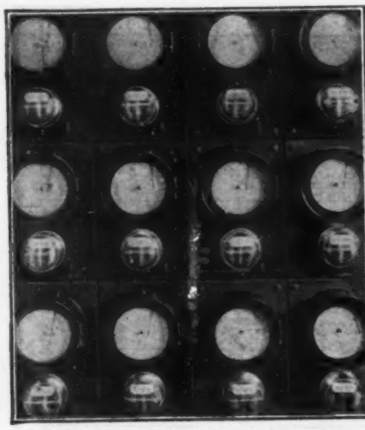




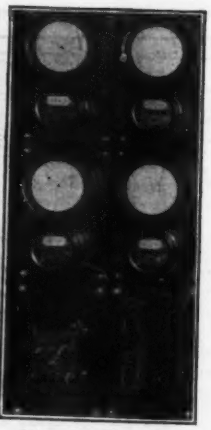
These Maps Will Help You



While in the Chicago-Milwaukee District



Panel Board in Chief Engineer's office of the A. O. Smith Corp., Milwaukee, Wisc.



Phoenix Knitting Mills, Milwaukee, Wisc.

Republic
Help Wisconsin

Savings a Few of Our Wisconsin Customers Have Obtained

$6,000.00 a year saving in fuel—Flambeau Paper Company, Park Falls, Wisconsin

"Our 18 Republic Flow Meters gave us accurate figures on the cost and consumption of our steam. They were partly instrumental in saving the addition of a 300 H.P. boiler, and in cutting our fuel cost about $6,000.00 a year. They are also effecting other savings by increasing the efficiency of our plant."

C. E. Wells, Chief Electrical Engr.

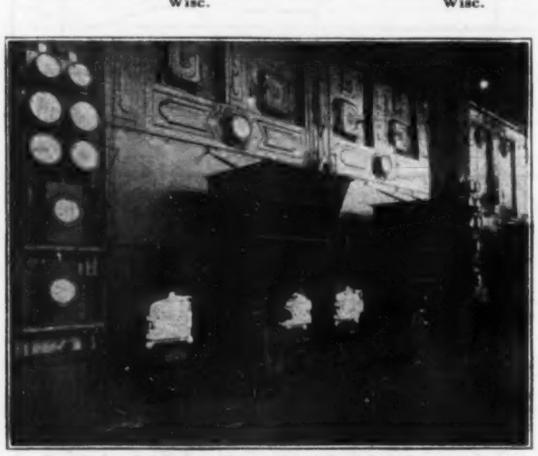
$20,000.00 Saved—A. O. Smith Corp., Milwaukee, Wisc.

"The 19 Republic Flow Meters used in connection with the A. O. Smith Corporation Steam Plant have proved very accurate and reliable. With their help we were able to increase the efficiency of our boilers so as to make unnecessary the installation of an additional boiler at a cost of $15,000.00 to $20,000.00."

"Our Republic meters told us that conditions were not right in four of our boilers. This led us to enlarge the throats in the bridge vaults from 4 ft. 6 in. to 8 ft. 7 in. We thus brought about a much better control of our fires with a more constant pressure, which saved us the installation of an additional 300 H.P. Boiler."

"A distinct advantage of the Republic equipment is that the bodies may be located any distance from the point of generation or distribution. The chief engineer of the power plant has the meters installed in his office, where he can see them at any time."

T. Chasty, Chief Engineer.



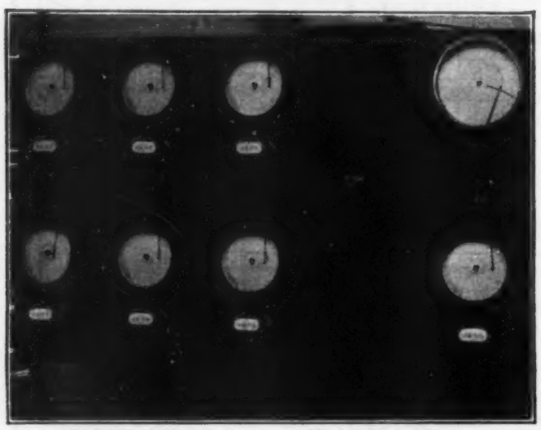
Boilers at the Gilbert Paper Co., Menasha, Wisc. equipped with Flow Meters, CO_2 Recorders, Draft and Pressure Indicators.

Firemen's Work Cut in Half—Marathon Paper Co., Rothschild, Wisc.

"We would not consider operating our power plant without the Republic Meters and our firemen would quit if we did. Our Republic Flow Meters have been the means of saving their cost many times over, by indicating the existence of many opportunities for effecting large savings in our power plant operation."

"The 24-hour graphic record of individual boiler operation together with the indicators on the boilers, tell us which boilers are carrying too heavy a load and which are loafing. Indicators also call attention to bad conditions within the boilers, such as dirty tubes, holes in the fire, foaming and priming, improper feed water regulations, etc." The savings here are over $6,000.00 yearly.

John A. Weiner, M.M.



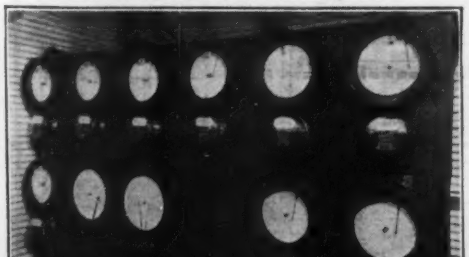
Panel Board in engine room, Nash Motors Corp., Kenosha, Wisc.

Republic Flow Meters Co.

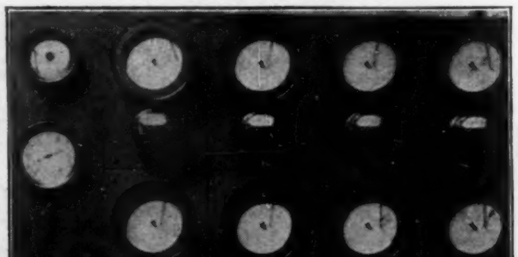
2232 Diversey Parkway **Chicago, Ill.**

Branches in 25 Principal Cities

Nothern Paper Mills, Green Bay, Wisc. A few of the 22 Steam Meters at this plant.



Dells Pulp & Paper Co., Eau Claire, Wisc. There are 15 Flow Meters and 2 CO_2 Recorders.



Thilmany Paper Co., Kaukauna, Wisc. 8 Flow Meters 7 CO_2 Recorders.